Aquaculture

Water Quality Management for Recirculating Aquaculture

Water quality is a term that reflects the overall ability of culture water to provide optimal growth conditions for the species of interest. Water source is the most critical consideration when determining a facility location and the production capacity of the system. Inadequate water quality and quantity will cause major issues in terms of production yields, fish health, and profit. While water quality can be remediated with filters and other treatment techniques, these options increase production costs. The following considerations should guide the decision to establish an aquaculture operation at a given location.

Biofilter

WATER SOURCE

Well Water – Well water is generally the best option for an aquaculture operation but should be tested for basic water quality parameters such as ammonia, iron, alkalinity, and a suite of contaminants like pesticides, heavy metals, and other toxins before a facility is built. Well water is typically free of any form of life or chemical contamination, but it's important to note that the aquifer is subject to the watershed use and chemistry of the underlying bedrock. Limestone bedrock produces water with high hardness and alkalinity, whereas granite bedrock will produce low alkalinity and hardness. Well water will generally be devoid of oxygen and may have other dissolved gasses like carbon dioxide, nitrogen gas, and hydrogen sulfide gas. The water must be aerated or degassed to atmospheric saturation levels before the water enters the culture unit. Other dissolved components such as iron and magnesium can also cause issues for fish. Aeration can help these components precipitate out of solution and return to non-toxic levels for fish, depending on age and species.

Municipal Water – Municipal water is typically treated with a chlorine and/or chloramine compound to kill any pathogens that may be present. These compounds are extremely toxic to both fish and the beneficial bacteria found in the biofilter of recirculating aquaculture systems. Chlorine and chloramine compounds must be removed from the municipal water before they come in contact with the culture water.

Surface Water – Ponds, lakes, and rivers contain insects, fish, amphibians, parasites, pathogens, pesticides, and organic or heavy metal contami-

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nants. The contents of surface waters create biosecurity concerns and should be avoided if at all possible. If there is no alternative water source, water should be filtered through a 20-µm screen or sand filter and then treated with a powerful oxidizer like hydrogen peroxide or ozone. This treatment should be followed by ultraviolet sterilization and activated carbon filtration before any surface water enters the facility. Contaminants in surface water are often cyclic in nature and must be continuously surveyed during the culture season when possible.

It may be prudent to use a distillation process or reverse osmosis (RO) filtration to ensure that only clean water enters the facility, especially if there are heavy metals or pesticides present. This style of filtration can be cost prohibitive, especially if large volumes of water are required. Keep in mind that certain salts (i.e., electrolytes), are required for fish to maintain optimal osmotic balance for reduced stress. Commercially available ocean salt mixes can be dissolved in purified water to create the proper salinity. Typical salinities for freshwater fish range from 0.5- to 8-parts per thousand (g/L).

Rain Water – Rain water is naturally distilled and will lack the hardness and various salts needed for osmotic equilibrium. Rain may be a good source of water, but it is also subject to atmospheric conditions. Pesticides and pathogens may be in the air, so rain water should be treated in a similar fashion to surface water to ensure that it is adequate to sustain life.

PHYSICAL PARAMETERS

Temperature – Water temperature affects metabolic and biochemical processes of the culture species and bacteria contained within the aquaculture system. No other physical factor affects the development and growth rates of fish as much as water temperature. Each species of fish has a temperature range it can tolerate. Within that range, there is an optimum temperature for growth and reproduction which may change as the fish grows. Many biological processes, such as spawning and egg hatching, are geared to natural annual changes in environmental temperature. Each 10°C temperature change has a two-fold effect on the metabolic rate of cold-blooded animals. For example, increasing water temperature 10°C will double the metabolic rate of an organism, which correlates to higher food consumption and growth rate as well as an increased biological oxygen demand (BOD). However, this relationship only holds true within the acceptable temperature range for any given species. Outside this temperature range, proteins and enzymes that perform essential metabolic processes of a given species begin to denature and break down such that they are no longer useful.

Submersible water heater

Like fish, pathogens have an optimum temperature range for development, and outbreaks are more prevalent during these conditions. Most chemical substances dissolve more readily as temperatures increase. In contrast, gases such as oxygen, nitrogen, and carbon dioxide become less soluble as temperature rises.

Temperature shock, caused by rapid temperature change, can stress fish and lead to death. This is most likely when fish are transported for stocking. It is important to slowly acclimate fish to the desired temperature in order to prevent shock. Prior to stocking, water in the transport container should be tempered with water from the tanks they will be stocked into. For small, sensitive fry, a temperature rate of 3.6°F (2°C) per hour is suggested. Larger, more hardy, fish can withstand more than a 9°F (5°C) per hour change in temperature. Tropical fish species can generally tolerate an increase in water temperature better than a decrease. The opposite is true for temperate and cool-water species. Fish that initially survive a temperature shock may be sufficiently stressed to later succumb to infection, disease, or parasites.

The physical and chemical properties of certain water components can be altered by changing water temperature. For example, the maximum amount of dissolved oxygen (DO) water can naturally hold decreases with increasing temperature (see Dissolved Oxygen on page 3). Additionally, the percentage of total ammonia nitrogen (TAN) that is in the toxic form increases with increasing water temperature and pH (Table 1.) (see Ammonia Nitrogen on page 3). For these reasons, it may be useful to maintain temperature and pH at the lowest end of the optimal range for any given species.

Table 1. Relative percentage of total ammonia nitrogen (TAN) in the toxic, unionized form at a given temperature and pH

	Temperature (°C)						
pH	**8**	**12**	**16**	**20**	**24**	**28**	**32**
7.0	0.2	0.2	0.3	0.4	0.6	0.8	1.0
8.0	1.6	2.1	2.9	3.8	5.0	6.6	8.8
8.2	2.5	3.3	4.5	5.9	7.7	10.0	13.2
8.4	3.9	5.2	6.9	9.1	11.6	15.0	19.5
8.6	6.0	7.9	10.6	13.7	17.3	21.8	27.7
8.8	9.2	12.0	15.8	20.1	24.9	30.7	37.8
9.0	13.8	17.8	22.9	28.5	34.4	41.2	49.0
9.2	20.4	25.8	32.0	38.7	45.4	52.6	60.4
9.4	30.0	35.5	42.7	50.0	56.9	63.8	70.7
9.6	39.2	46.5	54.1	61.3	67.6	73.6	79.3
9.8	50.5	58.1	65.2	71.5	76.8	81.6	85.8
10.0	61.7	68.5	74.8	79.9	84.0	87.5	90.6
10.2	71.9	77.5	82.4	86.3	89.3	91.8	93.8

Table 2. Dissolved oxygen (DO) concentration at saturation at a given water temperature

Temperature		Dissolved Oxygen Concentration (mg/L)
°C	**°F**	
0	32.0	14.6
2	35.6	13.8
4	39.2	13.1
6	42.8	12.5
8	46.4	11.9
10	50.0	11.3
12	53.6	10.8
14	57.2	10.3
16	60.8	9.9
18	64.4	9.5
20	68.0	9.1
22	71.6	8.7
24	75.2	8.4
26	78.8	8.1
28	82.4	7.8
30	86.0	7.5
32	89.6	7.3
34	93.2	7.1
36	96.8	6.8
38	100.4	6.6

Dissolved Oxygen – Dissolved oxygen (DO) is arguably the most important water quality parameter for fish survival. Concentrations of oxygen are expressed as parts per million (ppm) by weight, or milligrams per liter (mg/L). The concentration of DO per unit volume of water intrinsically becomes less as water expands at warmer temperatures. The equilibrium concentration of gasses achieved when water is exposed to the atmosphere for any given water temperature is called saturation. For example, the DO saturation level for water at 50°F (10°C) is 11.3 mg/L, whereas DO saturation at 86°F (30°C) is 7.5 mg/L (Table 2.). Systems that use liquid oxygen can cause excess levels of oxygen, known as supersaturation. Supersaturation of oxygen can be harmful because dissolved oxygen taken into the gills can return to a gaseous state, causing bubbles in the blood and leading to mortality. Aeration with air will only bring the DO concentration to the saturation level. Aeration is the only completely safe way to regulate DO concentration of water.

Most warm water fish require a minimum of 4 ppm and cold water fish require 5 ppm DO to achieve appropriate growth, reproduction, and health. Early life stages of fish are typically more able to survive oxygen deprivation than adult fish because of the relatively high ratio of gill surface area to body weight. In other words, juvenile fish are able to take up more oxygen per unit body weight than adult fish. Chronically low DO levels cause stress, increasing the chance of infectious diseases.

The most common usage of oxygen in aquatic organisms is for respiration. Respiration breaks down organic molecules like carbohydrates, liberating energy that is used to perform biological processes. The oxygen requirement for aquatic life is directly affected by the temperature and the biomass of all aquatic life in the system (fish, bacteria, etc.). Higher water temperatures and biomass have a higher BOD. Problematically, optimal growth rates occur at the upper end of a species temperature tolerance range, yet there is less oxygen available per unit of water at these higher temperatures. It therefore becomes more important to provide aeration at high water temperatures.

pH – Acidity, or pH, refers to the capacity of water molecules to donate hydrogen ions (H^+). Pure water has a neutral pH = 7.0, with pH 1 to 6.9 being acidic and pH 7.1 to 14 being basic or alkaline. The ideal pH for aquaculture is 7.0; the acceptable range is 6.5 to 9.0 for most aquaculture species. The pH has many implications for the biological and chemical processes that occur in an aquaculture system. Sudden changes in pH can stress the culture animals and kill beneficial bacteria in recirculating aquaculture system (RAS) biofilters. Increasing pH also increases the percentage of toxic unionized ammonia nitrogen (Table 1.). For this reason, it is important to maintain temperature and pH at the lowest end of the optimal range for any given species.

Fish have less tolerance of pH extremes at higher temperatures. Ammonia toxicity becomes an important consideration at high pH (see Ammonia Nitrogen on page 5), and hydrogen sulfide is more toxic at low pH. The pH of culture water is influenced by the amount of carbon dioxide present. Much of the CO_2 present is the result of animal respiration. Since CO_2 in water is an acidic substance, the pH of water will continually decrease over time without proper aeration. The amount of the pH fluctuation depends on the alkalinity or buffering capacity of the water. The addition of agricultural lime ($CaCO_3$) or baking soda ($NaHCO_3$) to the RAS increases the pH buffering capacity of the water.

Salinity – Salinity is a measure of the salt concentration of water and is typically expressed in parts per thousand (PPT) or grams per liter (g/L), but also may be measured in terms of specific gravity. Salts are inorganic molecules that easily dissolve into charged particles, or ions, when put into water. These ions formed from the dissociation of salts in water are critically important for many biological processes. The ions must exist in specific concentrations and ratios for animals to function properly. Some common salts are sodium chloride (NaCl), potassium chloride (KCl), calcium chloride ($CaCl_2$), and magnesium sulfate ($MgSO_4$). Knowing the salinity is extremely important for regulating salt balance (osmoregulation) to promote proper cellular function. Salt concentration typically occurs through diffusion of salt and water across fish gills and skin as well as active filtering through the kidneys.

Salts are used as a treatment for certain pathogens that are intolerant of salinity changes. Salts also cause fish to produce more mucus and slough off external parasites. Salt is used to reduce stress during hauling because it helps fish osmoregulate more easily since the blood and water salinities are the same. Each fish species has an optimal salinity level depending on its natural environment, and successful aquaculture operations must provide optimal salinity levels. Some species, such as salmon and barramundi, have a wide range of tolerable salinities because of their anadromous nature. Other species require water with a smaller salinity range.

Solids – When fish are fed, approximately 25% of their feed immediately becomes waste. Solid organic matter in recirculating systems is problematic for water quality and must be removed from the water as quickly as possible. Solids generally come in the form of fecal matter, dead and decaying organisms, and uneaten feed. Solids removal is important for avoiding water quality issues such as spikes in ammonia or oxygen deprivation. Solids come in all sizes. There are different management strategies for each size class.

Total Suspended Solids – Suspended solids are particles that are large enough to be filtered out of the water by mechanical filtration (using a filter screen, sand filter, swirl separator, etc.) and/or can be settled out of the water column given sufficient "quiet" time. Suspended solids include colloidal (0.001 to 100 µm dia.) and settleable solids (>100 µm dia.).

Settleable Solids – Settleable solids are those with great enough mass to be settled out of the water in a "quiet water" area with high retention time and low water velocity. These particles are the largest portion of the solids within the suspended solids category, having a diameter greater than 100 micrometers.


Granular sodium chloride salt

Dissolved Solids – Dissolved solids are microscopic in size and have characteristics that allow them to stay in solution regardless of settling or "quiet" time. These particles largely consist of proteins and amino acids, which are generally removed from the water by floatation. The stickiness of proteins forms bubbles in water, when aerated which can be removed from the system via capillary rise in the narrow gap between two surfaces using equipment like foam fractionators, also known as protein skimmers.

CHEMICAL PARAMETERS

Hardness – In municipal water, hardness is the measure of the water's capacity for precipitating soap. Soap is precipitated chiefly by calcium and magnesium ions, but also may be precipitated by hydgrogen ions or ions of metals such as aluminum, iron, manganese, strontium, and zinc. For aquaculture, hardness is important for larval fish development because the dissolved minerals in the water are used to create the skeleton and organs of the body and to aid in osmoregulation. For fresh water, hardness measures are related to the underlying geology of the area. Limestone bedrock tends to produce water with high hardness and alkalinity because of the calcium carbonate ($CaCO_3$) that is dissolved in the water. Hardness generally occurs in a 1:1 proportion to alkalinity, known as "carbonate hardness", but can be greater or lower than alkalinity depending on chemical composition of the water. Total hardness is usually not as important as total alkalinity in pond fish culture.

Alkalinity – Alkalinity is a measure of the dissolved carbonates in the water, or the ability of water to accept and neutralize acidity (hydrogen ions). This alkalinity measurement includes three forms of negatively charged carbon ions: carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and hydroxide (OH^-). Alkalinity and hardness are usually referred to in conjunction because the original measure of alkalinity is expressed in terms of equivalent concentrations of calcium carbonate ($CaCO_3$) needed to neutralize acidity, but alkalinity and hardness represent different types of measurements. Most waters of high alkalinity also have high hardness, but this is not always true.

Fish grow well within a wide range of alkalinity and hardness. Total alkalinity values in the range of 40 to 300 mg/L are ideal for promoting a strong biofilter and processing nitrogenous wastes. However, alkalinity greater than 300 ppm may begin to cause CO_2 buildup in the system at low pH, leading to fish health issues.

At low alkalinity, water loses much of its ability to buffer against changes in acidity. In RAS operations, the bacterial decomposition in the biofilter is an acidification process that can result in hazardous pH levels when alkalinity is low. Fish also may be more sensitive to some toxic substances such as copper at low alkalinity. The use of sodium bicarbonate (baking soda) to increase alkalinity levels is a relatively easy solution to this issue.

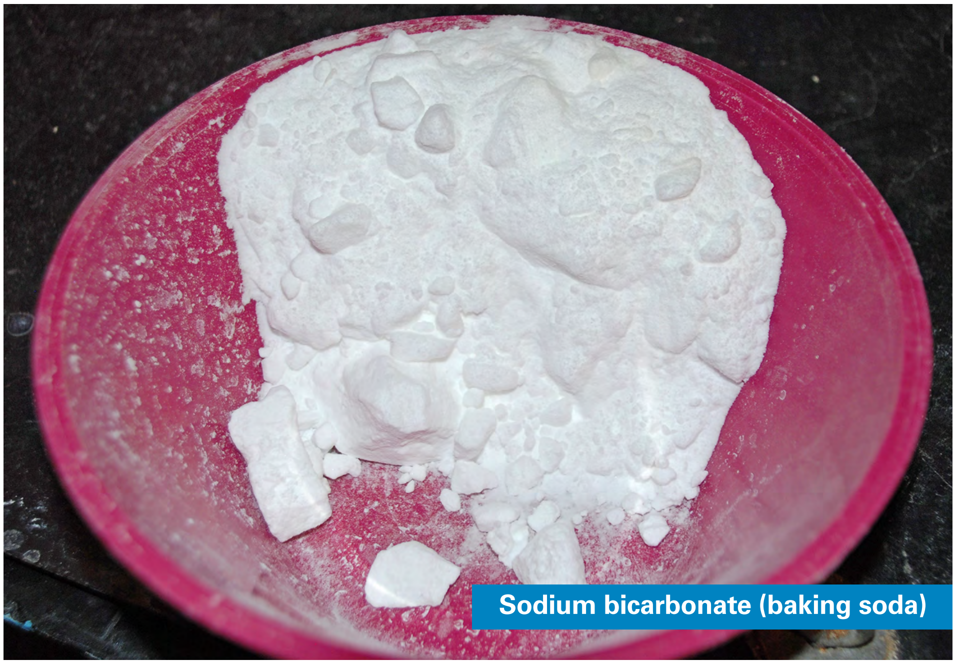
Nitrogen – Nitrogen is a major component of protein, and protein is a large component of fish feeds. The constant influx of protein means that nitrogen processing is critical to promoting healthy fish. Digested fish feed becomes waste that is excreted from the fish in the form of ammonia. Promoting nitrogen cycling through biofiltration rivals dissolved oxygen as the most important factor for fish survival and growth in recirculating aquaculture.

Ammonia Nitrogen – Ammonia is excreted into the water by fish as a result of protein metabolism. Some of the ammonia reacts with water to produce ammonium ions (NH_4^+). The remainder is present as un-ionized ammonia (NH_3). Un-ionized ammonia is more toxic to fish than ammonium. Standard analytical methods do not distinguish between the two forms; both are lumped as total ammonia nitrogen (TAN). The fraction of total ammonia that is un-ionized ammonia (NH_3) varies with salinity, dissolved oxygen, and temperature, but is determined primarily by the pH of the solution. For example, an increase of one pH unit from 8.0 to 9.0 increases the amount of un-ionized ammonia approximately 10-fold. These proportions have been calculated for a range of temperatures and pH values and are given in table 1. Note that the amount of NH_3 increases as temperatures and pH increase.

To calculate the un-ionized ammonia, determine the percentage from Table 3 by using the measured pH and temperature values. Un-ionized ammonia (ppm) = (ppm total ammonia x percentage of un-ionized ammonia) / 100.

The amount of un-ionized ammonia that is harmful to fish varies with species. In trout, 0.0125 ppm un-ionized ammonia will damage gills, kidneys, and the liver and reduce growth rates. These same observations occur in channel catfish exposed to un-ionized ammonia levels greater than 0.12 ppm. Although mortalities may not occur outright because of ammonia stress, chronic exposure to low levels of un-ionized ammonia may increase the chance of infectious diseases. Critical levels of un-ionized ammonia have not been determined for many aquaculture species, but it is best to maintain ammonia at the lowest possible level at all times.

Dealing with ammonia issues in water is a constant struggle, and it is much more problematic when fish are held at high densities with high feeding rates at high water temperatures. The metabolic rate of fish and beneficial bacteria is higher at warmer temperatures, so the rate of ammonia production and processing increases when temperatures rise within the species' optimal range. Beneficial bacteria use ammonia as a nitrogen source and alkalinity as a carbon source to feed themselves and grow. It is critical to provide adequate amounts of alkalinity to process ammonia when the ammonia levels are rising. One fast way to do this is by adding sodium bicarbonate ($NaHCO_3$), or baking soda, which dissolves quickly in water. Calcium carbonate ($CaCO_3$), or agricultural limestone, is also effective at raising alkalinity, but dissolves much more slowly and is best to add to the water prophylactically so that it can dissolve constantly. Maintaining alkalinity at around 100 mg/L will help ensure that nitrogen cycling occurs unhindered.


Sodium bicarbonate (baking soda)

One method of removing ammonia from water is to use a negatively charged mineral called zeolite. Zeolite can adsorb ammonium ions (NH_4^+) from the water. It is relatively ineffective at high pH when the ammonia is unionized (NH_3). Because ammonianitrogen is mostly in the non-toxic ionized form (NH_4^+) at low pH already, zeolite may not be extremely effective at reducing toxic, unionized ammonia (NH_3) issues. Additionally, high hardness and salinity can use up all binding power of zeolite, making it ineffective for removing ammonium ions.

When the ammonia level spikes quickly, the most effective way of reducing it is to perform a water exchange. It is important that the water used for this exchange has very similar temperature, salinity, and pH as the culture water, with no ammonia present. Keeping a large head tank of water adequate to perform a 100% water exchange of the system will greatly decrease the risk of crop failure due to ammonia toxicity.

Nitrite – Nitrite (NO_2^-) is the intermediate product of the oxidation of ammonia to nitrate, and it is also toxic to fish at high levels. The processing of ammonia to nitrate is generally performed by bacteria of *nitrosomonas* genus in fresh water. Nitrite enters the blood of fish across gill membranes where it combines with the oxygen-carrying portion of red blood cells (hemoglobin) to form a compound called methemoglobin, which cannot carry oxygen. Methemoglobin has a brown color that it imparts to the blood of fish suffering from nitrite poisoning. Nitrite poisoning thus has the name "brown blood disease." Because nitrite interferes with oxygen uptake by the blood, the symptoms of nitrite poisoning are quite similar to those caused by oxygen depletion, except the nitrite poisoning symptoms persist even when the DO is at saturation.

The nitrite concentration that is toxic to fish depends on the fish species, the amount of chloride ions (Cl^-) present in the water, and the quantity of dissolved oxygen. Rainbow trout become stressed at 0.15 ppm nitrite and die by 0.55 mg/L. Channel catfish are more resistant to nitrite, but 29 mg/L can kill them.

Nitrite is usually not a problem if there are three or more parts of chlorides present in the water for every part of nitrite. Chlorides do not affect the amount of nitrite in the water, but prevent the uptake of nitrite by the blood of the fish. Chloride is the same electronegativity and approximately the same size as nitrite, and it can compete with nitrite for uptake in the blood. Any time there is 0.1 ppm or more nitrite present, the water should be checked for chlorides to see if salt needs to be added. The addition of 25 ppm salt (NaCl) for each ppm nitrite has proven to be an effective treatment. A freshwater flush also is recommended to reduce nitrites.

Nitrate – Nitrate (NO_3^-) is the final metabolite of ammonia in the nitrification process. Processing of nitrite to nitrate is generally done by *Nitrobacter spp*. in fresh water. Nitrate is relatively non-toxic to fish. An acceptable level of nitrate for trout is below 250 ppm, whereas catfish can tolerate 400 ppm nitrate. Daily water exchanges at 10% of the total system volume are a standard practice in recirculating aquaculture to prevent the buildup of nitrate in the system. Because nitrate is the fully oxidized form of nitrogen, high oxygen levels must be maintained in all areas of the recirculating system to prevent reduction of nitrate back to nitrite or ammonia.

Nitrate is regulated in Iowa for environmental water quality and human health concerns, so effluent water leaving an aquaculture facility must meet certain criteria to be in compliance with the Clean Water Act (see “effluent considerations”).

Nitrogen Gas – Denitrification may occur in the absence of oxygen, causing the formation of nitrogen gas (N_2), which can be aerated out of the water and ventilated out of the facility. Dissolved nitrogen gas does not negatively affect fish at or below 100% saturation. However, supersaturation levels as low as 102% can cause gas bubble disease in fish. Gas bubble disease occurs when a dissolved gas emerges from solution and forms bubbles in the blood of a fish. Gas bubble disease can be caused by any supersaturated gas, but is usually caused by excess nitrogen. Any reduction in gas pressure or increase in temperature can bring nitrogen out of solution and form bubbles; the process is similar to the “bends” in scuba divers. These bubbles can lodge in blood vessels, restrict circulation, and result in death by asphyxiation. Gas supersaturation can occur when air is drawn in by a high pressure water pump or when air is injected into water under high pressure that is subsequently depressurized. Water that is heated or drawn from deep wells is potentially supersaturated. Ensuring high levels of aeration and ventilation will help prevent the formation and supersaturation of nitrogen gas in the water.

Carbon Dioxide – All waters, particularly ground water, contain some dissolved carbon dioxide. Almost all living organisms continuously add CO_2 to the water through respiration. CO_2 forms an acid when it is added to water, resulting in a pH decline. Conversely, pH increases when CO_2 is removed. Carbon dioxide can be a problem when associated with oxygen depletion, but usually is not a problem by itself unless it is present at extremely high concentrations (> 20 mg/L). When dissolved oxygen is limited, elevated CO_2 levels may interfere with the ability of fish to take up the remaining oxygen. Mechanical aeration along with proper ventilation in RAS operations can reduce high levels of CO_2.

The relationship among CO_2, pH, temperature, and alkalinity can be used to calculate CO_2 concentrations. Table 3 can be used to determine CO_2 levels from the pH, temperature, and total alkalinity (mg/L CO_3) of the water. Find the factor in the table that corresponds to the observed pH and temperature, and multiply this factor by the total alkalinity to find the CO_2 concentration. For example, at pH 7.4 and 68°F, alkalinity = 200 mg/L CO_3. The factor 0.084 is taken from the table, so 0.084 x 200 = 16.8 mg/L CO_2. Generally, waters supporting good fish populations have less than 5 mg/L CO_2. Carbon dioxide in excess of 20 mg/L may be harmful. If dissolved oxygen content drops to less than 5 mg/L, lower CO_2 concentrations may also be harmful.

Chlorine and Chloramine – Chlorine gas (Cl_2) is unstable and will aerate out of water within 24 hours when

Table 3. Multiplication factors to determine carbon dioxide from pH, temperature, and total alkalinity*. Multiply the factor in the table by the total alkalinity (mg/L) to obtain the carbon dioxide concentration (mg/L).

pH	Temperature						
	41°F	50°F	59°F	68°F	77°F	86°F	95°F
	5°C	10°C	15°C	20°C	25°C	30°C	35°C
6.0	2.915	2.539	2.315	2.112	1.970	1.882	1.839
6.2	1.839	1.602	1.460	1.333	1.244	1.187	1.160
6.4	1.160	1.010	0.921	0.841	0.784	0.749	0.732
6.6	0.732	0.637	0.582	0.531	0.493	0.473	0.462
6.8	0.462	0.402	0.367	0.335	0.313	0.298	0.291
7.0	0.291	0.254	0.232	0.211	0.197	0.188	0.184
7.2	0.184	0.160	0.146	0.133	0.124	0.119	0.116
7.4	0.116	0.101	0.092	0.084	0.078	0.075	0.073
7.6	0.073	0.064	0.058	0.053	0.050	0.047	0.046
7.8	0.046	0.040	0.037	0.034	0.031	0.030	0.030
8.0	0.029	0.025	0.023	0.021	0.020	0.019	0.018
8.2	0.018	0.016	0.015	0.013	0.012	0.012	0.011
8.4	0.012	0.010	0.009	0.008	0.008	0.008	0.007

* For practical purposes, CO_2 concentrations are negligible above pH 8.4

exposed to the atmosphere. Chloramine (NH_2Cl), on the other hand, is very stable in water and must either be filtered out by activated carbon, or broken up with a sulfur-containing compound like sodium thiosulfate or sodium sulfite (food grade). The chloramine molecule is a combination of chlorine and ammonia, and once it is broken up, both of those toxic chemicals are released into the water. Moreover, if sodium sulfite is the chosen de-chlorinator, dissolved oxygen will also be eliminated from the water and pH can decrease in poorly buffered water. To counter these effects, municipal water with chloramines can either be filtered through carbon filters or held for 24 hours in a holding tank with adequate sodium sulfite added (approximately 1 g per 10 gallons of water) to break up the chloramine and aeration to off-gas the chlorine. The holding tank may also contain biofiltration material to process the ammonia before it is allowed to enter the fish culture unit. The addition of sodium bicarbonate (baking soda) at a rate of ~0.5 grams per gallon (0.14 g/L) is also recommended in poorly buffered water. It is a good practice to chemically test water for the levels of free and total chlorine prior to releasing it into the culture water.

WATER QUALITY MONITORING

Good water quality is the goal for any aquaculture operation. Among the parameters most critical to monitor on a frequent or even constant basis are temperature, dissolved oxygen, and pH. Each species of fish has different tolerance ranges for each parameter used to quantify water quality. Tilapia are amongst the most tolerant fish species, whereas trout are amongst the most sensitive. The more sensitive a fish species is to poor water quality, the more important it is to monitor continuously.

Water quality probe

Manual Monitors – These options include chemical analysis and electronic probe methods for data collection. While chemical analysis is the least costly up-front for small-scale operations, it is quite time consuming and requires a competent, detail-oriented worker. Probe meters are a substantial initial investment ($2,000-$3,000), but they significantly decrease the time required to obtain an accurate reading and are ideal for medium-to-large aquaculture operations. Calibration is required for any probe, and they should be tested against known standards to evaluate the accuracy of the readings. Water quality probe technology is constantly improving, and calibrations and compensations for some systems are automated, which can decrease the skill, time, and maintenance required by workers.

Automated Monitors – Automated systems are ideal for large commercial-scale operations, especially those that need continuous monitoring. These systems utilize probes that are in-line in the plumbing with water flowing through them, or ones that are constantly submerged in water. Many systems are computer operated and have the capability of adding liquid oxygen, manipulating pH and temperature, exchanging water, etc. These systems are intended to reduce labor cost of monitoring and improve system control. However, automated systems are very expensive and can still fail, especially during a power outage. Manual monitoring, calibrating, and regular maintenance is required to ensure the accuracy of readings. For large operations, it is ideal to use a combination of automated and manual monitoring practices.

Continuous water quality monitor

Mechanical filtration with a rotating drum filter

EFFLUENT CONSIDERATIONS

The biofiltration process applied in RAS is a much more efficient and environmentally-friendly means of eliminating ammonia waste when compared to flow-through aquaculture systems, such as trout raceways, which may discharge waste water into the environment on a continuous basis. Solid waste generation is minimal when compared to other animal production system and can easily be captured in settling basins or be handled by waste water treatment facilities. Compared to other commercial animal production systems (beef, poultry, and swine), the waste generated from fish culture has considerably lower biological oxygen demand (BOD), total and suspended solids, and total nitrogen (TN) per pound. Most (75%-80%) of the nitrogen waste released from RAS occurs in the form of dissolved ammonia and nitrate. Filterable and settleable solids contain the majority (50%-85%) of the phosphorus discharge. With respect to other waste generation, another benefit to RAS effluent is that discharge is a steady and continuous extremely dilute solution containing relatively few solids.

Because the principles utilized in RAS biological filtration are similar to that of municipal wastewater treatment, effluent generated by aquaculture facilities is essentially pre-treated when discharged. Waste discharged from RAS has a far smaller impact on municipal water treatment process than traditional agriculture and livestock operations.

Nitrate is regulated in Iowa for environmental water quality and human health concerns, so the effluent water leaving an aquaculture facility must meet certain criteria to be in compliance with the Clean Water Act. The Iowa Department of Natural Resources (IDNR) and the Environmental Protection Agency (EPA) regulate the Total Maximum Daily Load (TMDL) of a variety of chemicals, including nitrate, in the water.

In Iowa, the TMDL is regulated by watershed, and the specific effluent allowances for any aquaculture facility are subject to local regulations. IDNR (www.iowadnr.gov/InsideDNR/RegulatoryWater.aspx), the Coalition to Support Iowa Farmers (www.supportfarmers.com/), or Iowa State University Extension (www.extension.iastate.edu) should be contacted for help with determining the regulations on an individual site basis.

Biofiltration material (Bio-barrels)

pH test kit

Water chemistry kit

REFERENCES

Cripps, S. J., and A. Bergheim. 2000. “Solids management and removal for intensive land-based aquaculture production systems.” *Aquacultural Engineering*, Vol. 22:1, pp. 33-56.

Ebeling, J. M., and B. Vinci. 2006. “Solids Capture.” *Recirculating Aquaculture Systems Short Course*. Accessed Jan. 21, 2015. https://ag.arizona.edu/.

Helfrich, L. A., and G. Libey. “Fish Farming in Recirculating Aquaculture Systems (RAS).” Accessed Jan. 21, 2015. www.aces.edu/dept/fisheries/aquaculture/documents/recirculatingVT.pdf.

Knepp, G. L., and G. F. Arkin. 1973. “Ammonia Toxicity Levels and Nitrate Tolerance of Channel Catfish.” The Progressive Fish-Culturist 35:4, pp. 221-224. Taylor & Francis 1973.
DOI: 10.1577/1548-8659(1973)35[221:ATLANT]2.0.CO;2.

Timmons, M. B., J. M. Ebeling, F. W. Wheaton, S. T. Summerfelt, and B. J. Vinci. August 2002. Recirculating Aquaculture Systems, 2nd edition.

Westin, D. T. 1974. “Nitrate and Nitrite Toxicity to Salmonoid Fishes.” The Progressive Fish Culturist 36:2, pp. 86-89.
DOI: 10.1577/1548-8659(1974)36[86:NANTTS]2.0.CO;2.

Yeo, S. E., F. P. Binkowski, and J. E. Morris. August 2004. Aquaculture Effluents and Waste By-Products: Characteristics, Potential Recovery, and Beneficial Reuse. North Central Regional Aquaculture Center Pub. No.119. Accessed Jan. 21, 2015.
www.ncrac.org/oldfiles/NR/rdonlyres/1CAA8F76-19B8-4511-97CA-20CF3D59D55F/0/AquacultureEffluents.pdf.

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Bottom photo of pH test kit, page 9.

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