SRAC Publication No, 461

Southern
Regional
Aquaculture
Center

November 1991

Water Quantity and Quality Requirements for Channel Catfish Hatcheries

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Simple and inexpensive production of seed stock is a key to successful aquaculture. Indeed, the rapid growth of commercial channel catfish culture is owed in no small part to the ease with which large numbers of channel catfish fry can be produced using relatively unsophisticated hatchery technology.

Although the production of channel catfish fry is technically a simple process, success in some hatcheries is poor year after year. Problems may include poor egg matchability, low fry survival, poor fry growth, or a high incidence of infectious diseases of eggs or fry. Sometimes these problems are related to poor management practices, but quite often they are the result of poor water quality within the hatchery.

With appropriate treatment, any water can be made suitable for use in a catfish hatchery. Cost of treatment is often not economically justifiable. It is usually good practice to use a source that provides, as nearly as possible, water of correct quality for optimum matchability of eggs and survival and growth of fry. Good water quality is maintained in the hatchery by providing adequate water flow and aeration to hatching and rearing troughs. Frequent removal of uneaten feed and other accumulated organic debris will also aid in maintaining proper rearing conditions within troughs or tanks.

Water sources

In many regions, water from several sources may be available for use in the hatchery. Sources may include ground waters from aquifers lying at different depths and various surface water supplies. Before the hatchery is built, the manager should become familiar with the quality and availability of these potential hatchery water supplies. The best water supply may then be selected by comparing desired water quality and flow requirements with the chemical characteristics, temperature, and availability of various water sources.

The success of other hatcheries using water from a common source is the best indicator of the suitability of a particular water. Obviously, if poor water quality at other hatcheries is causing low survival of eggs or fry, or if costly treatment is required to make the water suitable for use, then it may be wise to seek an alternative water source. If there are no other hatcheries in the area and the quality of the water supply is questionable, a pilot-scale hatchery can be constructed to ensure that the water is suitable for use.

Ground water

Ground water generally is considered to be the best source of water for catfish hatcheries. Ground waters are usually free of suspended matter, pollutants, and fish disease organisms. Temperature and chemical composition are relatively constant, and, in regions with abundant ground water, the supply is dependable. The chemical composition and well pumping rates for some ground water supplies may be obtained from well logs for existing nearby wells. Alternatively, a test well can be drilled to assess the source. The quality of most ground waters is relatively constant over time, so a single chemical analysis will suffice to characterize water quality. Nevertheless, it is good practice to have the supply reanalyzed every year or two.

Although ground waters are preferred for hatcheries, some waters may have to be treated to make them suitable for use. Depending upon the water, treatments may include:

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- aeration to increase dissolved oxygen concentrations;
- degassing to reduce total gas pressure and remove carbon dioxide and hydrogen sulfide;
- temperature regulation using water heaters or mixing of waters of different temperatures;
- sedimentation and filtration to remove iron; and
- addition of calcium to waters of low hardness.

Surface waters

Surface water supplies include streams and rivers, ponds, lakes, and reservoirs. Unpolluted surface water offers several advantages over ground water as a hatchery water supply. For example, dissolved oxygen concentrations tend to be near saturation; dissolved carbon dioxide and hydrogen sulfide concentrations are usually low; total gas supersaturation is seldom a problem; and iron concentrations are usually very low. Nevertheless, all surface water supplies suffer the disadvantages of variable quality and availability with time and exposure to sources of pollution and turbidity. For these reasons, carefully evaluate any surface water before use as a hatchery water supply.

Because quality and availability vary over time, historical record is necessary to predict whether the water will be suitable. Such records are not available for most waters, however, and changes in water temperature, chemical composition, and water availability caused by unusual weather events cannot be predicted by records. The best advice is to use common sense and avoid those waters that may become unsuitable for use during the time the hatchery is in operation.

Another major constraint to using surface water for hatcheries is the potential for contamination by fish disease organisms or water-borne predators. Most surface waters have a resident fish community. The fish in the water supply may serve as a reservoir for fish disease organisms that could enter the hatchery and cause major losses. Natural predators of catfish fry, such as wild fish, insects, and other invertebrates, can also enter a hatchery and cause losses of fry.

Water quantity requirements

The success of a hatchery will suffer if insufficient water is available, even if that water is of optimum initial quality. Low water flow rates through hatching and rearing troughs allow waste products to accumulate which may quickly cause deterioration of water quality.

The typical trough (Figure 1) used for egg hatching and fry rearing holds roughly 100 gallons of water and is about 8 feet long, 2 feet wide and 10 inches deep. Troughs this size can hold 10 spawns at a time without crowding. Although the number of eggs per spawn varies with the size of the female brood fish, the ten spawns will contain (as a rough average) a total of 200,000 eggs. After the fry begin feeding, hold only about 100,000 fry in a trough of these dimensions. Thus, in a traditionally managed hatchery, two fry rearing troughs are available for each egg hatching trough.

Experience has indicated that minimum water turnover time (defined here as trough volume in gallons divided by water flow in gallons per minute) in hatching and rearing troughs should be about 40 minutes. Thus for a single 100 gallon trough, water flow should be a minimum of 2.5 gallons per minute. Larger troughs require proportionately higher flow rates. More water flow is also needed when egg or fry densities are higher.

Over a 10-to 12-week spawning season, each set of three 100-gallon troughs (one for eggs, two for fry) could be expected to produce roughly 1 to 1.5 million fry and would require a minimum flow of 7.5 gallons per minute (three troughs times 2.5 gallons/minute per trough). A hatchery capable of producing about 10 million fry per spawning season will typically contain 21 to 30 troughs and require a minimum water flow to the hatchery of 50 to 75 gallons per minute.

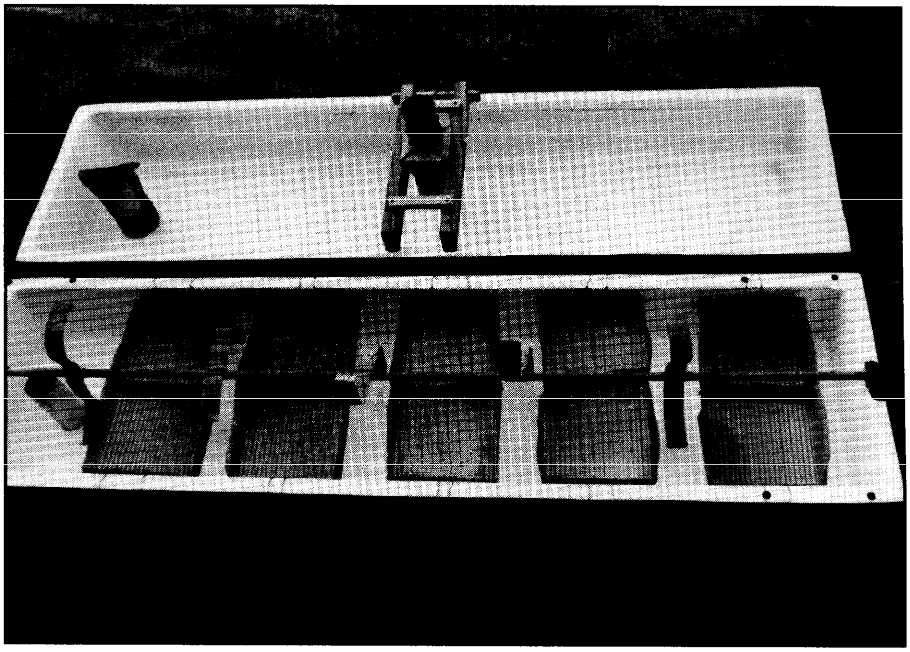

Figure 1. Traditional equipment used in a channel catfish hatchery: a fry rearing trough (top) with a 1/20-horsepower electric agitator and an egg hatching trough (bottom) with egg baskets and paddles.

The calculations above represent minimum flows. It is good practice to use at least twice those flow rates (turnover times of 20 minutes) to ensure against deterioration of water quality within hatcheries. Additional water flow is particularly important during the peak of the spawning season when the number of spawns arriving at the hatchery and the number of fry being reared temporarily exceeds the planned hatchery capacity. Thus, as a rough guide, a hatchery expected to produce 10 million fry per season should be supplied with roughly 100 to 150 gallons of water per minute.

Water quality requirements

Some of the more important water quality requirements for hatchery water supplies are discussed in the following sections. Aside from these specific requirements the water should also be:

- free of pesticides, solvents, petroleum products, and other pollutants;
- free of fish disease organisms;
- of relatively constant quality and availability.

Temperature

The optimum temperature range for development of eggs and rearing of fry is between 78 and 82°F (26 to 28°C). If the temperature is too low, hatching and development are prolonged, and fungi, which thrive in cool waters, often invade the egg mass. At higher water temperatures, embryos develop too fast and there may be a high incidence of malformed or nonviable fry. Also, bacterial diseases of eggs or fry and channel catfish virus disease of fry are more common if the water temperature is greater than 82°F (28°C).

Considerable energy is required to heat or cool water, and it is usually too costly to attempt major changes in water temperature. Therefore, the temperature of the water supply should be near 80°F before it enters the hatchery.

Ground water from deep wells (500 to 1,000 feet deep) is warmed by the internal heat of the earth and may be suitable for use in channel catfish hatcheries without temperature modification. Water from shallow wells (less than 300 feet) and some surface waters are too cool to use directly. Cool ground waters can be impounded in a small reservoir pond where solar heating will raise the temperature to some extent.

Nevertheless, water temperatures in the reservoir pond and in most other surface waters will vary with local weather conditions and still may be too cool for use early in the spawning season. An in-line water heater can be used to ensure a minimum temperature in the inlet water. The opposite condition may be encountered late in the spawning season when surface waters become too warm for use in hatcheries. It is very expensive to cool large volumes of water using refrigeration or chiller units, The best method of reducing water temperature is to mix the water that is too warm with cool water (such as water from a shallow well) to achieve the correct temperature.

Dissolved oxygen

Adequate dissolved oxygen is critical in hatcheries because eggs and fry have high metabolic rates and thus a high requirement for oxygen. Dissolved oxygen concentrations should not fall below 4-5 ppm at any time within the hatchery. Proper management of dissolved oxygen involves two distinct considerations: (1) ensuring that the water is oxygenated before use and (2) providing adequate aeration in hatching and rearing units to maintain optimal levels of dissolved oxygen throughout the hatchery.

Waters deficient in dissolved oxygen should be aerated before use. Pre-aeration not only ensures adequate initial levels of dissolved oxygen, but also may benefit some waters by partially degassing waters supersaturated with total dissolved gases and by removing some carbon dioxide and hydrogen sulfide. The two most common systems for pre-aerating water supplies for catfish hatcheries are packed column aerators (Figure 2) and aeration of water in an aeration tank.

Properly designed packed columns are highly effective aerators and relatively inexpensive to operate. They offer an added advantage of being good degassing devices for waters supersaturated with total dissolved gases. Packed columns are filled with a high surface area plastic packing. Influent water is evenly distributed at the top of the column and flows down over the packing in a thin film where gas exchange with the atmosphere occurs. Various plastic materials have been used as packing media and materials specifically designed for use in packed columns are commonly available from aquaculture supply companies.

Specific design criteria for packed columns are based upon water flow, water temperature, dissolved gas concentrations in the influent water, and desired dissolved gas concentrations in the effluent. These considerations are discussed in detail in appropriate references listed at the end of this report. As a rough guide, a packed column 4 to 6 feet high and about 30 inches in diameter will be sufficient to pre-aerate water for a catfish hatchery supplied with 100 gallons per minute of anoxic, 80°F groundwater.

As an alternative to packed columns, influent water maybe pumped into a metal or fiberglass tank and oxygenated with surface aerators or underwater diffusers. In such a system considerable initial aeration can be accomplished by running the influent water onto a splashboard or through an expanded metal grate to break the flow into small drops. The aeration tank should be large enough to provide adequate water residence time for aeration, but the appropriate tank volume will

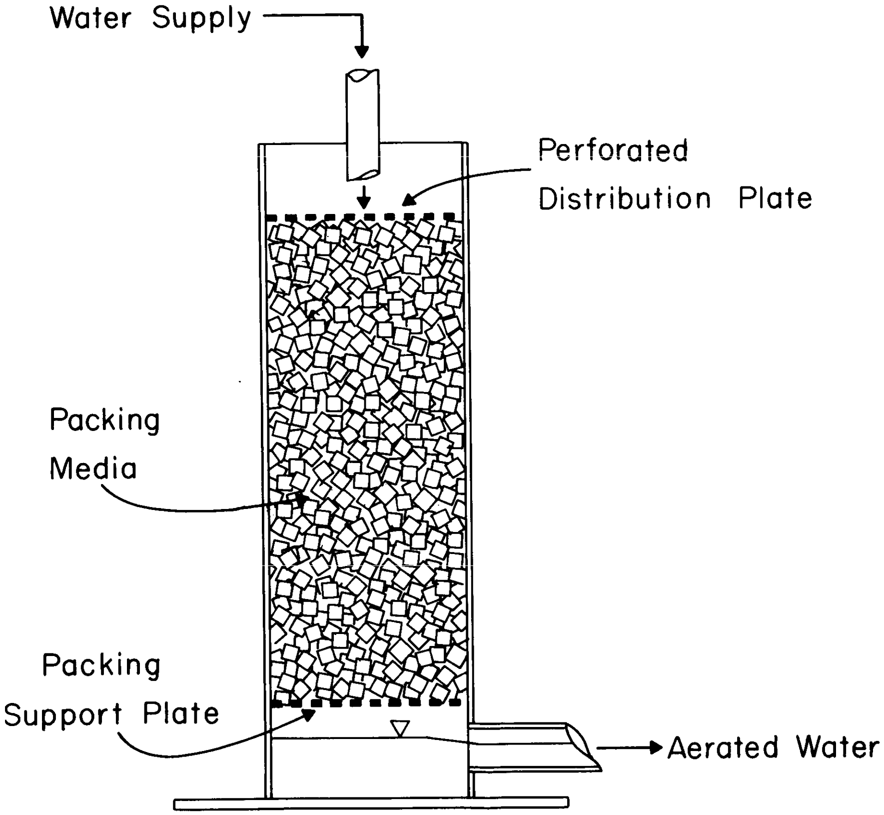

Figure 2. Cross section of a simple packed-column aerator.

depend upon the type and size of aerator used. Some experimentation may be required to find the best combination of tank volume and aeration device; the goal is generally to achieve an effluent dissolved oxygen concentration exceeding about 5 ppm.

As a starting point, pre-aeration tanks used in many existing catfish hatcheries provide a turnover time of 10 to 15 minutes (a capacity of 1,000 to 1,500 gallons for a water flow of 100 gallons per minute). Water is aerated with one or two 1/3-horsepower surface agitators (Figure 3).

Some type of aeration device must be provided to each trough within the hatchery to replenish dissolved oxygen lost as eggs or fry respire. Again, some trial and error may be necessary to find the right size and type of aerator. Common practice is to provide one 1/20 horsepower surface agitator per 100-gallon fry rearing trough. The agitators should be covered with small-mesh screening to prevent injury to fry.

Water circulation, in addition to adequate dissolved oxygen, is important in egg hatching troughs because oxygenated water must flow around and through the egg mass to ensure that all eggs receive sufficient dissolved oxygen. A common sign of inadequate water circulation in hatching troughs is the presence of dead eggs in the center of the egg mass. Those areas may serve as foci for fungal or bacterial infection. Slowly rotating paddles in egg hatching troughs serve both to aerate and circulate the water through the egg mass. Vigorous aeration with diffusers (air stones) may also be used to aerate and circulate water in hatching troughs. Air flows and the size and placement of diffusers must be determined through experience.

Carbon dioxide

High levels of dissolved carbon dioxide interfere with respiration by eggs and fry. Ideally, water supplies for catfish hatcheries should not contain measurable levels of dissolved carbon dioxide, but concentrations up to at least 10 ppm seem to be well tolerated, provided that dissolved oxygen concentrations are adequate. Some groundwaters may contain in excess of 20 ppm dissolved carbon dioxide and should be vigorously aerated to drive off some of the gas.

Total gas pressure

Total gas pressure is a measure of the “concentration” of all gases dissolved in water. It is expressed in pressure units such as millimeters of mercury (mm Hg). When total gas pressure in water exceeds local barometric pressure, water is supersaturated and gas will tend to leave the water by diffusion or by forming bubbles. Gas bubble trauma (also called gas bubble disease) may occur in fish living in gas-supersaturated water when gases in the blood or tissues come out of solution and form bubbles. The bubbles can block blood flow or damage tissues.

Instruments called “saturometers” are used to measure total gas pressures. Values are usually expressed as delta-P, which is the total gas pressure in water compared to local barometric pres-

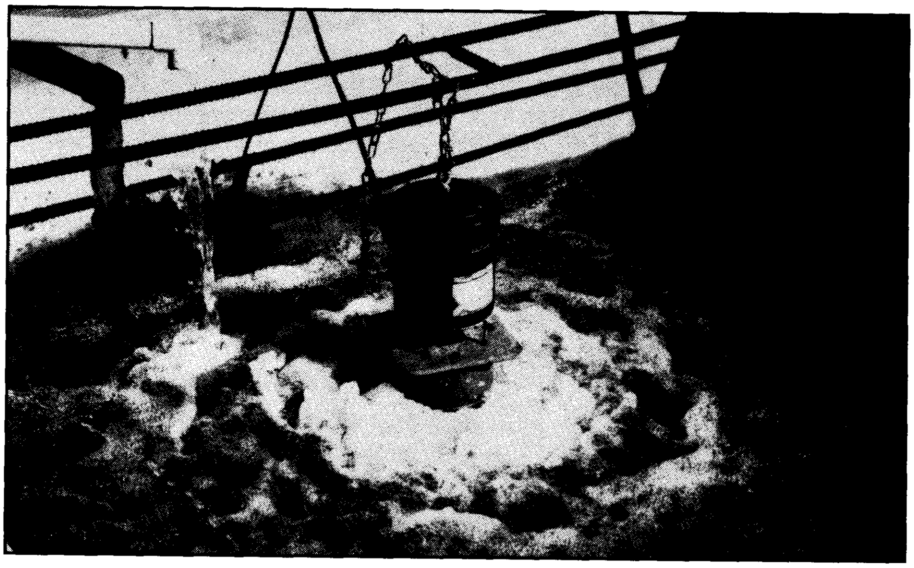

Figure 3. A 1/3-horsepower surface agitator used to oxygenate water in a pre-aeration tank.

sure. Positive delta P values mean the water is supersaturated. Saturometers are not commonly available to catfish hatchery managers, but supersaturated conditions can sometimes be diagnosed by the formation of bubbles on the surface of tanks or the milky appearance of water as gases come out of solution.

Channel catfish eggs are fairly resistant to high delta P-values because the naturally high pressure within the eggs helps prevent bubble formation. Eggs appear to withstand delta P-values at least as high as 100 mm Hg with no adverse effects. At high delta P-values, bubbles may form on and in the egg mass causing it to float high in the egg hatching basket. The top of the egg mass may be above water and will tend to dry out. Dislodging the bubbles by shaking and rotating the mass will temporarily alleviate the problem, although decreasing the delta P of the water is the best solution. Quite often, however, the first indication of supersaturated conditions is death of fry.

Clinical signs of gas bubble trauma in catfish fry include loss of equilibrium, abnormal swimming and gas bubbles in the yolk sac, behind the eyes, or on the skin. The bubbles prevent normal swimming and feeding and fry may become trapped at the surface. In severe cases, newly hatched fry rapidly die as blood flow is restricted or the yolk sac ruptures. Gas bubble trauma may occur in fry when delta P-values exceed about 70 to 80 mm Hg. To be safe, delta P-values should not exceed about 40 mm Hg in channel catfish hatcheries.

Gas supersaturation can be caused by a variety of natural and manmade conditions. Many groundwaters and some surface waters are naturally supersaturated. Surface water gas supersaturation is common below dams where air is entrained in the spillway overflow or when water is heated in electrical generating facilities. Gas supersaturation can also be caused within the hatchery water supply system.

The most common cause of supersaturation in supply systems is entrainment of air from a leak in the pipes on the suction side of a water pump. Some of the gases in the entrained air are driven into solution as the water is pressurized after moving through the pump. In those situations, it is often possible to hear air bubbles moving through elbows and valves in the delivery system. Heating water can also cause considerable increases in delta P unless the water is degassed after heating. The increase in delta P attributable to heating can be substantial: if water is heated from 70°F to 80°F, delta-P increases by more than 60 mm Hg.

Pre-aeration of the influent water is commonly used to reduce supersaturation to tolerable levels. Packed column aerators are particularly effective at degassing supersaturated waters, but other types of systems providing vigorous aeration may be used. Be aware, however, that underwater diffused aeration (air bubbled through airstones) is relatively inefficient at degassing waters and, in some systems, may actually cause supersaturation. If supersaturation is caused by air leaks in the water supply line, the first course of action is to locate and repair the problem.

Salinity

Salinity is the dissolved salt content of water and is often expressed as the parts of salt by weight per thousand parts of water by weight (ppt). Channel catfish can breed and reproduce over a wide range of salinities. Eggs can hatch and fry will develop in waters with salinities up to at least 8 parts per thousand, but the optimum salinity for channel catfish hatchery supplies appears to be between 0.5 and 3 ppt (500 to 3,000 ppm).

Hardness

Hardness refers to the amounts of calcium and magnesium in the water and is expressed as ppm of equivalent $CaCO_3$. Adequate concentrations of environmental calcium are required for "hardening" of eggs and for normal bone and tissue development of fry. Symptoms of environmental calcium deficiency include swelling and poor matchability of eggs and slow development, lack of vigor, poor stress resistance, and low survival of sac fry.

A minimum of 5 ppm calcium hardness is required for adequate egg matchability and for development and vigor of sac fry. Higher calcium concentrations are desirable because calcium also protects fry from ammonia and metal toxicosis. All things considered, hatchery water supplies should contain at least 20 ppm calcium hardness. Calcium levels can be increased by adding a solution of calcium chloride to the water supply. The calcium solution can be added by chemical metering pumps or by using an inexpensive “drip system” where a concentrated solution of calcium chloride is slowly dripped into the pre-aeration system.

Alkalinity

Alkalinity is a measure of the capability of water to neutralize acids. In most natural waters, the predominant bases are bicarbonate and carbonate. Alkalinity is expressed as ppm equivalent $CaCO_3$. Catfish eggs and fry thrive in waters with a wide range of alkalinity, although waters of very low alkalinity (<10 ppm as $CaCO_3$) should be avoided as hatchery supplies if possible. These waters are poorly buffered and pH can fluctuate drastically with small additions of acid or base. More importantly, dissolved metals such as copper and zinc are very toxic to fry in waters of low alkalinity. Copper and zinc can leach from pipes used to plumb the hatchery water distribution system.

pH

pH expresses the intensity of the acidic or basic character of the water. The pH scale is usually represented as ranging from O to 14. Conditions become more acidic as pH values decrease and more basic as they increase. At 77°F, pH 7.0 is the neutral point. The pH of most fresh waters is a function of total alkalinity and dissolved carbon dioxide concentration. Generally, if levels of those two variables are within the desired range, pH will be between 7.0 and 8.5, which is the desired pH range for incubating eggs and rearing fry.

An important exception to this general rule exists when surface waters containing dense submersed plant communities are used as a water supply. During sunny afternoons, rapid carbon dioxide removal by photosynthesizing plants may cause pH values to temporarily rise above pH 9. In extreme instances, values well above pH 10 have been recorded. Exposure to pH-values above 9 are undesirable and even short-term exposure to waters of pH 10 or above may kill fry and reduce egg matchability. Vigorous aeration of such waters will add some carbon dioxide to the water and somewhat reduce the pH, but this reaction is not rapid enough to be effective in extreme circumstances. The best solution is to avoid the use of surface waters that contain dense stands of submersed plants.

Ammonia

Un-ionized ammonia is quite toxic to channel catfish sac fry and early swim-up fry. Ideally, water in rearing troughs should be free of ammonia for optimal health and growth of fry, and the maximum concentration of un-ionized ammonia that should be allowed is about 0.05 ppm NH_3-N. Above this concentration, fry develop more slowly and are more susceptible to infectious diseases.

Removing ammonia from water supplies is difficult, so waters containing appreciable ammonia should not be used to supply catfish hatcheries. Ammonia is a product of fish metabolism, and ammonia production can be significant when high densities of fry are held in rearing troughs. Ammonia levels in rearing troughs can be decreased by either decreasing fry density or increasing water flow to flush the troughs.

Iron

Most surface waters contain very low concentrations of iron. Some anoxic ground waters, however, contain considerable iron in a dissolved form. When the water is aerated the iron is oxidized to a rust-colored precipitate of iron oxide. Dissolved iron is considered to be of relatively low toxicity to most aquatic organisms. Solid precipitates of iron oxide are even less toxic but may coat the gills of fry and interfere with respiration. Dense precipitates of iron oxide also may cover eggs and hinder gas exchange and suffocate the eggs. Total iron concentrations should be less than about 0.5 ppm for hatchery water supplies.

The simplest system used to remove iron is to pump the water into a small reservoir pond (0.5 to 1 acre) where the dissolved iron is oxidized and some of the iron oxide precipitate settles out. Some of the remaining precipitate can be removed using sand filters. An alternate method is to oxidize the iron by vigorously aerating the water in a tank or chamber prior to sand filtration. Complete removal of iron is difficult regardless of the system used.

Hydrogen sulfide

Hydrogen sulfide gives water a “rotten-egg” odor and is very toxic to channel catfish fry. Sac-fry will be killed when exposed to as little as 0.005 ppm hydrogen sulfide. Avoid using waters containing appreciable hydrogen sulfide. If this is not possible, hydrogen sulfide should be removed from water before it enters the rearing trough. Vigorous aeration will remove some hydrogen sulfide by volatilization and by oxidation of the sulfide to sulfate, which is nontoxic.

Treatment processes

The most common water quality problems encountered in channel catfish hatcheries and the treatment processes required to correct those problems are summarized in Table 1. But remember, it is often easier to seek an alternative water source rather than add expensive treatment systems in an effort to make a particular water suitable for use.

Table 1. Common water quality problems in channel catfish hatchery water supplies.

Variable	Desired level	Problem	Solution
Temperature	78-82°F	too low	reservoir pond for solar heating or use water heaters
		too high	blend with cooler water
Dissolved oxygen	5 ppm to saturation	too low	vigorous aeration of incoming water and supplemental aeration in troughs
Carbon dioxide	less than 10 ppm	too high	vigorous aeration (degassing) of incoming water and supplemental aeration in vats or troughs
Total dissolved gases	delta P less than 40 mmHg	too high	vigorous aeration (degassing)
Calcium hardness	more than 20 ppm as $CaCO_3$	too low	addition of calcium chloride to water supply
Ammonia (un-ionized)	less than 0.05 ppm NH_3-N	too high	do not use as a water supply; avoid accumulation within hatchery by decreasing fry density or increasing water flow
Iron	less than 0.5 ppm total iron	too high	aeration (oxidation) followed by precipitation or sand filtration
Hydrogen sulfide	less than 0.005 ppm H_2S-S	too high	vigorous aeration (degassing) of incoming water

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The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 89-38500-4516 from the United States Department of Agriculture.

NRAC Fact Sheet No. 170-1993

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An Introduction to Water Chemistry in Freshwater Aquaculture

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The major water quality factors that are important in freshwater aquaculture systems and methods to monitor them are described in this publication. Water quality determines not only how well fish will grow in an aquaculture operation, but whether or not they survive. Fish influence water quality through processes like nitrogen metabolism and respiration. Knowledge of testing procedures and interpretation of results are important to the fish farmer.

Some water quality factors are more likely to be involved with fish losses such as dissolved oxygen, temperature, and ammonia. Others, such as pH, alkalinity, hardness and clarity affect fish, but usually are not directly toxic. Each water quality factor interacts with and influences other parameters, sometimes in complex ways. What may be toxic and cause mortalities in one situation, can be harmless in another. The importance of each factor, the determination method and frequency of monitoring depends upon the type and rearing intensity of the production system used.

Water Quality Variables

Temperature

All biological and chemical processes in an aquaculture operation are influenced by temperature. Fish adjust their body temperature and metabolic rate by moving into cooler or warmer water. Each species has a preferred or optimum temperature range where it grows best. At temperatures above or below optimum, fish growth is reduced. Mortalities may occur at extreme temperatures.

Dissolved Oxygen

The minimum dissolved oxygen (DO) level that fish can safely tolerate depends upon temperature and to a certain extent the species. Volubility of oxygen increases as temperature decreases. In ponds, DO can change dramatically over a *24* hour period. During the day oxygen is produced by photosynthesis, the process by which green plants convert water and carbon dioxide in the presence of light, to oxygen and carbohydrates. During the night and day oxygen is consumed by respiration, the process by which plants and animals use oxygen to produce carbon dioxide as they burn carbohydrates, but in the day photosynthesis usually produces more oxygen than is used. Typically, oxygen levels are lowest just before dawn and highest in the late afternoon.

DO in a culture system must be maintained above levels considered stressful to fish. Warmwater fish (species that grow best at temperatures above 80°F) can tolerate lower DO concentrations than coldwater fish (species that grow best at temperatures below 60°F). As a rule of thumb, DO should be maintained above 3.0 ppm (parts per million; frequently used interchangeably with milligrams per liter, mg/L) and 5.0 ppm for warm and coldwater fish, respectively. Prolonged exposure to low, nonlethal levels of DO constitutes a chronic stress and will cause fish to stop feeding, reduce their ability to convert ingested food into fish flesh, and make them more susceptible to disease. Intensive fish production in ponds, cages, flow-through, and recirculating systems requires aeration or oxygenation to maintain DO at safe levels.

Nitrogenous Wastes

Most fish and freshwater invertebrates excrete ammonia as their principle nitrogenous waste. Analytical methods are used to determine total ammonia-nitrogen (TAN). The proportion of TAN that exists in ionized and un-ionized form varies with pH and temperature. As pH and temperature increase, the amount of TAN in the toxic un-ionized form increases (see figure 1). Fish continuously exposed to more than 0.02 ppm of the un-ionized form may exhibit reduced growth and increased susceptibility to disease.

When fish are cultured intensively and fed protein-rich feeds they can produce high concentrations of ammonia in the water. Ammonia and other metabolic wastes are gradually removed by natural processes in ponds or through the use of biological filters in recirculating and reuse systems. Ammonia is removed by bacteria that initially convert it into nitrite and subsequently into nitrate. Nitrite is toxic to fish and causes "brown blood" disease. Concentrations of 0.5 ppm have reduced growth and adversely affected fish. Fish can tolerate nitrate to several hundred ppm. Removal or detoxification of ammonia is facilitated by providing and maintaining an optimal environment for the appropriate bacteria (pH between 7-9; temperature approximately 75-85° F).

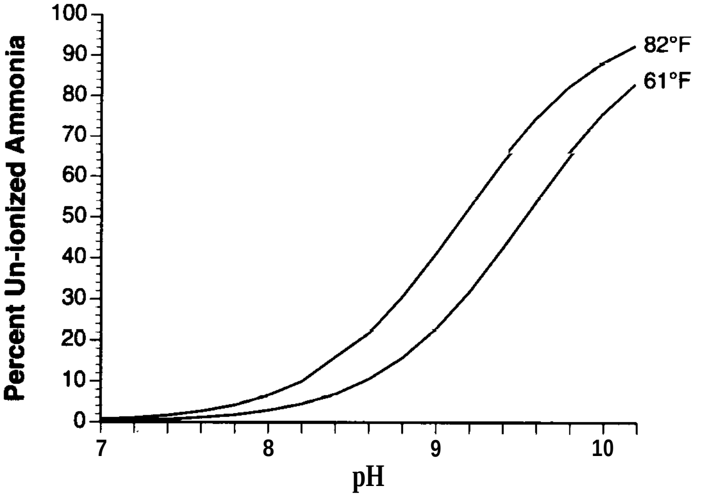

Figure 1. Relationship between pH, temperature, and un-ionized ammonia at 61°F and 82°F

pH

The concentration of bases and acids in the water determines its pH. A low pH is acidic and a high pH is basic; a pH of 7 is neutral. Fish survive and grow best in waters with a pH between 6-9. If pH readings are outside this range, fish growth is reduced. At values below 4.5 or above 10, mortalities occur.

In well-buffered ponds (with alkalinity over 50-100 ppm, see next section), pH typically fluctuates one or two units daily. In the morning, carbon dioxide levels are high and pH is low as a result of respiration during the night (carbon dioxide forms a mild acid when dissolved in water). After sunrise, algae and other green plants produce carbohydrates and oxygen from carbon dioxide and water by photosynthesis. As carbon dioxide is removed from the water, its pH increases. The lowest pH of the day is typically associated with the lowest level of dissolved oxygen. The highest pH of the day is typically associated with the highest level of dissolved oxygen.

In recirculating systems, vitrification and respiration of both fish and biofilter bacteria decrease pH. Frequently, a buffer such as sodium bicarbonate is added to prevent the pH from falling too much.

Alkalinity

The buffering capacity of culture water, expressed as ppm calcium carbonate, is its alkalinity. Alkalinity is a measurement of carbonate and bicarbonate ions (ions are atoms or groups of atoms with a negative or positive charge) dissolved in the water. As the amount of carbon dioxide fluctuates, the pH of water changes. The magnitude of this shift is determined by the water's buffering capacity or its ability to absorb acids and/or bases. Photosynthetic activity in a poorly buffered pond can cause pH to increase, perhaps from as low as six in the morning to nine or more by late afternoon. In a pond with higher alkalinity, the pH shift is reduced. For instance, the daily shift in a well buffered pond might be from a pH of seven in the morning to eight by late afternoon. A suitable range of alkalinity is 20 to 300 ppm. Alkalinity in excess of 300 ppm does not adversely affect fish, but it does interfere with action of certain commonly used chemicals (e.g., copper sulfate). Alkalinity remains relatively constant in ponds, but decreases steadily in nonsupplemented, recirculating systems. Alkalinity can be increased by adding agricultural limestone to ponds or sodium bicarbonate to recirculating systems.

Hardness

Calcium and magnesium ions comprise hardness. Test procedures usually determine both ions as "total hardness," expressed as ppm calcium carbonate. In most waters the concentrations of alkalinity and hardness are similar, but they can differ vastly as alkalinity measures negative ions (carbonate, bicabonate) and hardness measures positive ions (calcium, magnesium). Hardness is important, especially in the culture of several commercial species such as striped bass and catfish. If hardness is deficient, these species do not grow well. Hardness should be above 50 ppm; low hardness can be adjusted by the addition of lime or calcium chloride.

Carbon Dioxide

Only when using groundwater, transporting fish at high densities, or in recirculating systems are carbon dioxide problems likely to develop. At high concentrations, carbon dioxide causes fish to lose equilibrium, become disoriented and possibly die. Testing groundwater before use and aerating it, if necessary, will reduce carbon dioxide to acceptable levels. Careful planning, aeration or oxygenation, and buffering of water will keep carbon dioxide at acceptable levels when large numbers of fish are hauled extended distances or cultured in recirculating systems.

Salinity

The total concentration of all ions in the water is its salinity. Freshwater fish exhibit a range in salinity tolerance. Many commercially important species (e.g., channel catfish, *Ictalurus punctatus;* largemouth bass, *Micropterus salmoides;* tilapia, *Tilapia* sp.) survive and grow well in slightly salty water. After they smelt, salmon and trout can tolerate salt water. Salinity not only affects osmoregulation it also influences the concentration of un-ionized ammonia. During the planning stage of an aquaculture operation, salinity should be measured and the water's appropriateness determined.

Iron

Many groundwaters contain elevated levels of dissolved iron. When exposed to the air, this iron interacts with oxygen, becomes insoluble, and forms a red deposit. Small clumps of iron are produced that can settle on fish gills, causing irritation and stress. Problems can be avoided if the iron-bearing water is exposed to air and the resultant clumps of iron removed by settling or filtration before the water enters the culture system.

Chlorine

To control bacteria, municipal water supplies are typically treated with chlorine at 1.0 ppm. If municipal waters are used to culture fish, residual chlorine must be removed by aeration, with chemicals such as sodium thiosulfate, or filtration through activated charcoal. Chlorine levels as low as 0.02 ppm can stress fish.

Hydrogen Sulfide

Ponds with oxygen-poor bottoms and accumulated organic material can release hydrogen sulfide when seined or disturbed. Substratum beneath heavily fed cages/net pens can accumulate wastes (e.g., uneaten food, feces) and produce hydrogen sulfide gas if oxygen becomes deficient. Hydrogen sulfide gas has a rotten egg odor and is extremely toxic to fish. Any detectable odors or levels should be avoided and extreme care should be taken when handling fish in an afflicted pond. Ponds can be drained, exposed to air and/or excavated to correct the problem.

Water Clarity

In pond and cage culture, water clarity can affect fish. If fish that prefer turbid waters (e.g., bullhead, catfish, walleye) are cultured in relatively clear water they will experience stress; survival and growth will be adversely affected. Accumulation of suspended solids and discoloration of culture water occur in recirculating systems which can irritate fish and precipitate disease. Some suspended and dissolved materials can cause off-flavor in fish. Filtration and flocculent can be used to remove solids and reduce discoloration.

Monitoring Methods

A variety of methods are available to monitor water quality (see Table 1). In pond, cage, and low intensity culture, the high precision of sophisticated analytical methods (e.g., APHA 1989) is not needed to make informed management decisions (see Boyd 1990). However, intensive culture in recirculating and reuse systems requires frequent and sophisticated monitoring.

If fish are maintained at high densities, then temperature, dissolved oxygen, ammonia, nitrite, and pH should be monitored daily or more frequently (e.g., continuous monitoring of dissolved oxygen in recirculating systems). Water clarity, alkalinity, and hardness can be measured less frequently, perhaps one or two times per week, as they do not fluctuate as rapidly. Salinity, iron, and chlorine should be determined when a potential water source is first examined so corrective measures may be incorporated into the production system during the design or planning stage. Carbon dioxide should be measured when first using a new groundwater source and routinely in recirculating systems. When hydrogen sulfide and carbon dioxide problems are likely, systems should be monitored closely and the means to correct problems should be readily available.

At lower stocking densities, water quality parameters can be monitored less frequently or not at all. Regardless of the frequency, monitoring should be conducted at a standard time and depth where fish are located. Time of measurement and observed values should be recorded; good record keeping is essential to successful aquaculture. In pond and cage culture it is preferable to monitor dissolved oxygen early in the morning, when conditions stressful to fish are most likely to occur (e.g., low oxygen). Conversely, temperature and pH in ponds are best measured during the late afternoon.

Sources of Supplies and Equipment

Several suppliers produce kits and materials to monitor water quality. Suppliers frequently have displays at trade shows and sources are listed in several trade journals including the Annual Buyer's Guide published by Aquaculture Magazine, P.O. Box 2329, Ashville, NC 28802.

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Acknowledgments

This work was supported by the Northeastern Regional Aquaculture Center through grants number 89-38500-4356 and 90-38500-5211 from the Cooperative State Research Service, U.S. Department of Agriculture. Any opinions, findings, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the U.S. Department of Agriculture.

Table 1. Water quality factors, commonly used monitoring procedures, and preferred ranges for fish culture. Details for specific test procedures can be obtained from a commercial supplier or appropriate text (e.g., APHA 1989; Boyd and Tucker 1992).

Water Quality Factor	**Test Procedure**	**Preferred Ranges for Fish Culture**
Temperature	Thermometer, Telethermister	species dependent
Dissolved Oxygen[1]	Titrimetric (Modified Winkler) Polarographic meter Calorimetric kits	>4-5 ppm for most species
Total Ammonia-Nitrogen[2] (ionized and un-ionized)	Calorimetric kits (Nesslerization or Salicylate) Ion specific probes	NH_3<O.02 ppm
Nitrite[2]	Calorimetric kits (Diazotization) Ion specific probes	<1 ppm; 0.1 ppm in soft water
pH[3]	Calorimetric kits Electronic meter	6-8
Alkalinity	Titrimetric with pH meter Titrimetric with chemical indicator	50-300 ppm calcium carbonate
Hardness	Titrimetric kit	>50 ppm, preferably >100 ppm calcium carbonate
Carbon dioxide	Titrimetric	<10 ppm
Salinity[4]	Conductivity meter Refractometer Titrimetric	species dependent typically <0.5- 1.0 ppt (for freshwater fish)
Iron	Colofimetric kit Visible red precipitate	<0.5 ppm
Chlorine	Calorimetric kit	<0.02 ppm
Hydrogen sulfide	Calorimetric kit	No detectable level
clarity[5]	Secchi disk Turbidimeter	species dependent

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1. The Winkler method is relatively complicated and time consuming, but may be appropriate if the culture system is small and financial resources are limited. Dissolved oxygen meters are quick and convenient to use, but expensive and require regular maintenance to function correctly. Calorimetric samplers or kits are reasonably accurate and suitable for field analyses, but sometimes difficult to interpret at night with limited light. If multiple readings are frequently taken, a polarographic meter is the preferred method.

2. Ion-specific probes require expensive and sophisticated instrumentation; they are impractical in commercial situations. One possible exception is a computer monitored, intensive recirculating system. A variety of moderately priced calorimetric kits are available to monitor ammonia and nitrite. Greatest precision is obtained with a spectrophotometer. If fish are cultured at high densities, ammonia should be monitored by precise analytical methods (e.g., APHA 1989; Boyd and Tucker 1992).

3. Meters are available over a wide range of prices. Performance depends upon daily calibration and regular maintenance. Calibration is done with known standards called buffers. Calorimetric tests lack the precision of a meter, but are quick, economical, and adequate for field analyses.

4. Conductivity measures the water's capacity to convey an electrical current; it is directly related to the concentration of ions in the water. Distilled water has a conductivity of 1 µmhos/cm; natural waters range from 20 to 1,500 µmhos/cm. Conductivity meters are widely available and relatively inexpensive. Refractometers measure the salinity of a water sample optically; they are expensive and most accurate in brackish or salt water.

5. A Secchi disk (metal plate 6" in diameter with diagonal quadrants painted white and black) is lowered until it disappears, the depth of Secchi disk visibility. If a Secchi disk is not available, you can use your hand. In reuse and recirculating systems, a turbidimeter can be used and clarity expressed as Jackson Turbidity Units (JTU) or Nephelometric Turbidity Units (NTU).

SRAC Publication No. 4601

Southern
Regional
Aquaculture
Center

January 2002

Measuring Dissolved Oxygen Concentration in Aquaculture

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Dissolved oxygen concentration (DO) is considered the most important water quality variable in fish culture. In the broadest sense, however, dissolved oxygen concentration is no more important than other environmental variables because any factor that is outside the range tolerated by fish can cause stress or death. What makes dissolved oxygen concentration so important in intensive fish culture is the speed with which it can change. Over a matter of hours, or sometimes even minutes, DO can change from optimum to lethal levels. No other critical environmental variable in fish culture is so dynamic.

The dynamic nature of dissolved oxygen results from the interaction of three factors. First, oxygen is not very soluble in water so water has only a limited capacity to "hold" oxygen. Second, the rate of oxygen use by fish, plankton and organisms living in the pond mud can be high. Third, oxygen diffuses very slowly from the atmosphere into undisturbed water. The combination of these three factors—limited solubility, rapid use and slow replenishment—can cause rapid changes in dissolved oxygen concentrations.

Dissolved oxygen levels can be managed with aeration, but the response time for taking corrective measures is short. This makes it critical to have a rapid and reliable method of measuring dissolved oxygen concentrations so that aeration devices can be activated when needed.

There are a number of ways to measure dissolved oxygen concentration. Select a method based on 1) the number of ponds or tanks to be measured, 2) the level of accuracy required, and 3) the cost of the measurement technique.

The titration-based "drop count" method fairly rapidly assesses whether or not there is sufficient dissolved oxygen in water. The drop count method is inexpensive and appropriate if DO concentration is to be measured infrequently in a few ponds or tanks. However, on commercial fish farms or in any other situation where DO measurement of many ponds or culture units is routine, a dissolved oxygen meter is an indispensable piece of equipment.

What is an oxygen meter?

An oxygen meter has two components—the sensor (sometimes called the probe) and the meter. Various types of sensors are available, but they all operate in basically the same way: the sensor reacts with oxygen and an electrical signal is produced in proportion to the oxygen concentration. The signal is then amplified, translated into concentration units, and displayed by the meter. The meter circuitry also compensates the reading for changes in temperature, altitude or salinity. The meter circuitry may also include features to aid in calibration.

Most DO sensors operate as electrochemical cells with a positive electrode (cathode) and a negative electrode (anode) connected by a "salt bridge" consisting of a saturated electrolyte solution. In most sensors, oxygen passes through a permeable membrane and is chemically reduced within the sensor. The chemical reduction of oxygen generates an electrical current that is processed by the electronic components within the meter and displayed as a DO concentration. The current is proportional to the concentration. Thus, DO meters do not measure oxygen concentration directly, but measure a voltage that is produced by the chemical reactions of oxygen with the various components of the sensor.

Types of dissolved oxygen sensors

Polarographic or Clark sensors use gold or platinum as the cathode and silver as the anode (Fig. 1). Polarizing voltage is applied to the cathode to cause the reduction of oxygen within the sensor.

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*Mississippi State University

Oxygen is consumed at the cathode according to the reaction: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$. In response to the production of hydroxyl ions (OH^-) at the anode, and in order to preserve the charge balance of the electrolyte (saturated KCl) solution, chloride ions react with silver at the anode according to the reaction: $Ag^o + Cl^- \rightarrow AgCl$. Therefore, the chloride ions in the electrolyte solution function as a "carrier" of the electric potential.

Galvanic sensors use silver or platinum as the cathode and lead, iron or zinc as the anode. Application of a polarizing voltage is not necessary because the reduction of oxygen in the presence of the sensor materials is spontaneous. Thus, a galvanic sensor is like a battery (fuel cell) that is fueled by oxygen. Galvanic sensors typically have faster response times than polarographic sensors and are more expensive.

Fiber optic oxygen sensors consist of an optical fiber with a sensor tip that contains a thin layer of oxygen-sensitive fluorescent dye dissolved in pure silicon. The optical fiber carries blue light from a light-emitting diode (LED) to the sensor. This stimulates the dye to emit fluorescent light that travels back up the optical fiber to a photodetector. Oxygen diffusing into the sensor tip binds to the fluorescent dye, which reduces ("quenches") the intensity of light emission. The extent of quenching is directly related to oxygen concentration. Fiber optic sensors are very sensitive at low DO concentrations. Fiber optic sensors are sensitive to ambient light, but this problem can be overcome by coating the sensor tip with silicon. However, this silicon overcoat will reduce probe response time.

Which oxygen meter is best?

Many different oxygen meters are commercially available (see list of manufacturers below), and each model has a unique combination of features that makes it more or less suitable for a particular application. The best meter for occasional use in an indoor setting, such as a hatchery, will be quite different from the one that is best for regular use under rough, outdoor conditions. The purchase decision is further complicated by the fact that good meter systems are expensive, primarily because precious metals are used in the construction of many sensors. Before buying a meter, consult with other fish farmers, Extension specialists, aquaculture supply companies, and meter manufacturers to identify the most suitable one.

Some of the desirable features of a dissolved oxygen meter suitable for making field measurements include:

- accuracy
- rapid response
- ease of calibration
- water resistance
- sturdy, rugged construction
- automatic temperature compensation
- manual salinity compensation
- manual barometric pressure compensation
- measures from 0 to 200 percent saturation
- easily changed cable or probe

Other desirable features may include:

- at least a 25-foot cable
- a digital, liquid crystal display that can be read in bright sunlight or in total darkness
- an integral membrane cap assembly
- a built-in calibration chamber/storage sleeve
- storage of measured values in memory within the meter (datalogging)
- an RS-232 personal computer interface
- a "hold" or "auto-read" function indicating that a stable reading has been attained
- a battery charger

Operating an oxygen meter

It is beyond the scope of this publication to provide detailed operational instructions for each of the many kinds of meters. Carefully read the instructions that come with the meter to understand how it works and how to use it properly. Remember, the number displayed by the meter is not necessarily accurate. The number on the display is correct only when the meter has been properly calibrated, the measurement is made correctly, and the sensor and meter have been properly maintained. One common step in the use of most meters is calibration, and some details of this process are presented in the next section.

Calibrating an oxygen meter

Dissolved oxygen meters do not measure dissolved oxygen concentration directly, but measure an electrical current that is proportional to dissolved oxygen concentration. Therefore, the meter must be standardized to a reference condition that compares an electrical current to a known DO concentration. The most common reference condition is the oxygen concentration of air saturated with water vapor (100 percent humidity).

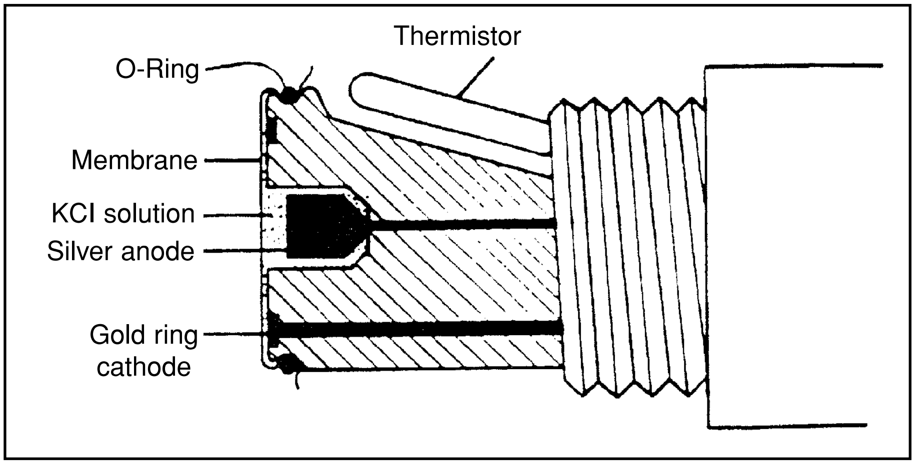

Figure 1. A cross section of a typical polarographic dissolved oxygen sensor.

There are several techniques for calibrating meters. Consult the operations manual for specific instructions. Moist air calibration is the simplest and most straightforward method. The following guidelines describe moist air calibration of dissolved oxygen meters with commonly used polarographic sensors. Dissolved oxygen meters should be calibrated before each use.

(1) Inspect the sensor for bubbles under the membrane, and tears or fouling of the membrane.

Bubbles prevent proper meter calibration and cause readings to fluctuate erratically. Before placing the membrane on the sensor tip, lightly tap the probe body while holding the probe vertically upright to dislodge bubbles formed when filling the probe body with electrolyte solution. Replace the membrane if bubbles are present (Fig. 2). Wipe the membrane with a smooth cloth to remove water drops from the membrane surface.

(2) Place the sensor in a bottle with a moist sponge or paper towel in the bottom.

Calibration must occur in an environment in which the surrounding air is saturated with water vapor. Otherwise, calibration will be inaccurate and DO measurements will be erroneous.

(3) Turn the instrument on.

If the instrument does not activate, check the condition of the batteries.

(4) Zero the meter.

Adjust the display to read zero.

(5) Polarize the sensor in the calibration mode of the meter.

It takes about 15 minutes to completely consume the oxygen in the electrolyte solution behind the membrane and fully polarize a polarographic sensor. For the most accurate measurements, the sensor should be polarized and the meter calibrated at a temperature as close to the pond water temperature as possible. Adjust the displayed value of dissolved

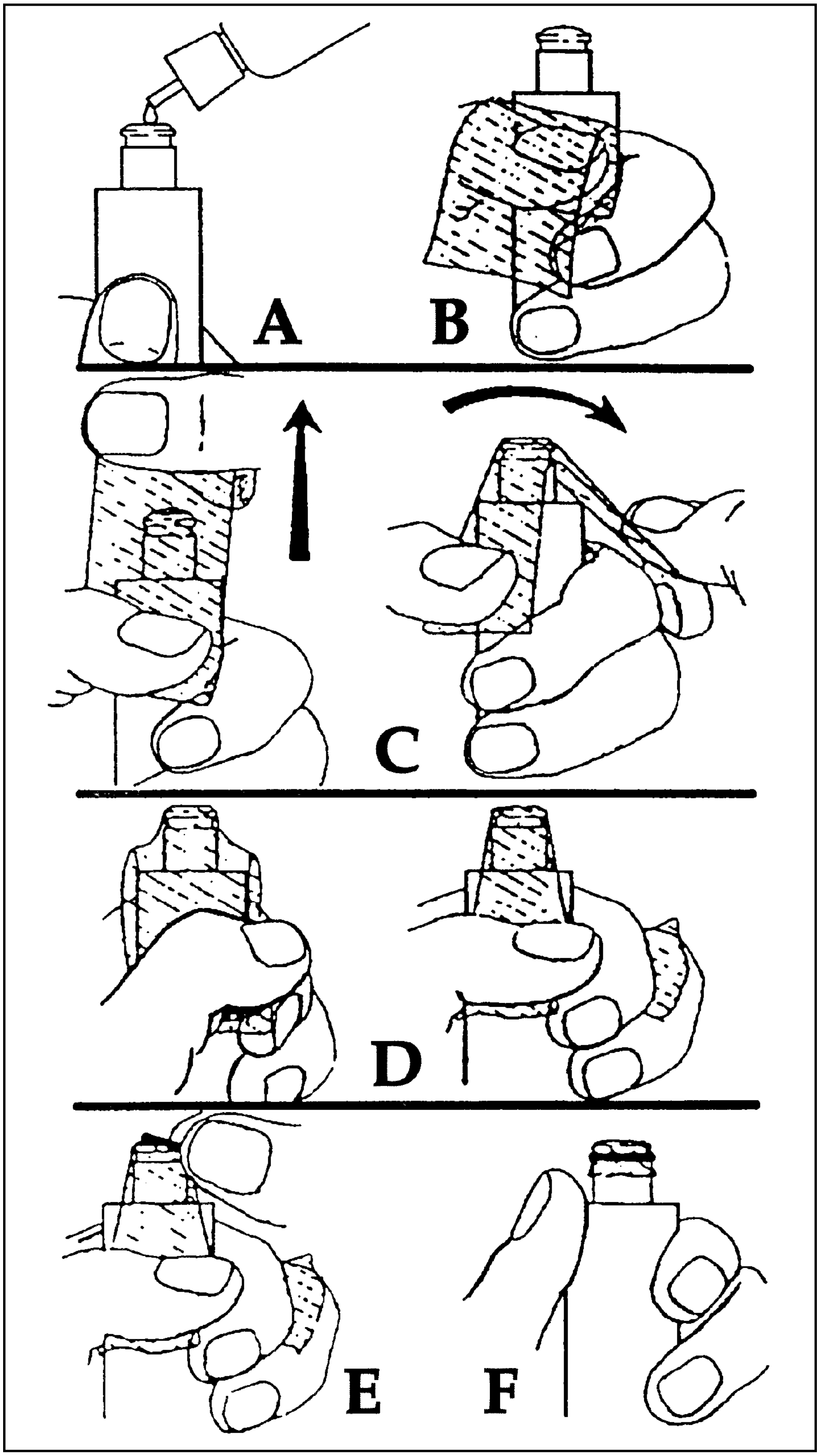

Figure 2. Sequence for installing a membrane on a polarographic dissolved oxygen sensor.
A - Fill the sensor body with electrolyte solution.
B - Hold a membrane between the thumb of your left hand and the sensor body.
C - With your other hand, stretch the membrane up, over and down the other side of the sensor body.
D - Secure the membrane to the sensor body under your forefinger.
E - Roll the O-ring over the sensor tip; pull out any wrinkles that may occur; check for trapped bubbles.
F - Trim excess membrane from sensor tip.
(Figure courtesy of YSI Incorporated.)

oxygen to 100 percent saturation. If the displayed value slowly drifts lower, the sensor is not yet fully polarized.

Some DO meters must be calibrated based on the saturation concentration of dissolved oxygen (in mg/L). Determining the DO concentration at saturation requires measuring air temperature and salinity and knowing the local altitude. Some DO meters have tables on the back of the meter or in the manual that show the saturation concentrations of dissolved oxygen as a function of temperature and salinity.

(6) Switch the mode of the meter from calibration to that used to read dissolved oxygen concentration.

Making dissolved oxygen measurements

The process of measuring dissolved oxygen concentration with an oxygen meter is simple, although it involves a bit more than simply putting the sensor in the water and reading a number on the display. Be sure to read the instructions for the meter carefully as the procedure can vary somewhat depending on the type of sensor being used.

Accurate measurement of DO concentration with polarographic sensors requires moving the sensor in the water. Oxygen is consumed across the membrane, so failure to move the sensor will create an oxygen-depleted microzone around the sensor tip and show a measurement that is too low. Move the sensor up and down or side to side about 1 foot per second to prevent this problem. The response of dissolved oxygen sensors is not instantaneous. Measured values will change rapidly at first and then begin to stabilize within 15 to 20 seconds, although it is rare that measured values in ponds will fully stabilize.

Dissolved oxygen measurements made near the pond bank are very different (usually lower) than those made in open areas of the pond because of the effects of sediment respiration and pond bank vegetation. Some fish farmers attach the sensor cable to a pole, leaving about 1 to 2 feet of the cable and sensor to hang from one end of the pole, in order to measure farther from the bank (Fig. 3).

Other fish farmers tie the sensor to a small float (such as a seine float) so that the sensor dangles a foot or so beneath the float. The float and sensor are tossed from the pond bank out into the pond and then slowly retrieved while reading the meter. It is difficult to obtain an accurate measurement of DO concentration using this method because it is usually not possible to pull the rig through the water long enough for the displayed value to stabilize. Nonetheless, this approach is preferable to measurements made near the pond bank and millions of pounds of fish have been successfully raised using this technique. The success of this approach is not based on accuracy but on the fact that this method always shows a DO concentration that is too low. By systematically erring on the low side, the pond can be aerated before dissolved oxygen concentration becomes critical.

Figure 3. The cable connecting the dissolved oxygen meter to the probe can be attached to a pole to make measuring easier.

Typically, the DO concentration of a number of ponds or tanks is measured during a brief time. The dissolved oxygen meter should not be turned off between measurements to avoid depolarizing the probe. If the meter is not going to be used for about 1 hour, turn off the meter to extend the life of the batteries and the sensor. Recalibrate the meter when it is used again. If a large meter adjustment is necessary during recalibration it may be an indication of problems with the membrane or sensor.

Dissolved oxygen sampling programs

When an oxygen meter is maintained properly and used according to the manufacturer's instructions, extremely accurate measurements can be made. However, aquaculture systems are dynamic, and a single measurement of dissolved oxygen, no matter how accurate, may have no practical significance because it represents just one of many possible values that can vary over time and from place to place, even in well-mixed, continuously aerated systems such as tanks or raceways. For example, feeding activity increases oxygen uptake by fish, so concentrations of dissolved oxygen decrease shortly after fish are fed. Also, pronounced gradients of dissolved oxygen concentration often exist along raceways because fish use oxygen as the water passes through each raceway section.

Using an oxygen meter correctly is often the easy part of implementing a good dissolved oxygen monitoring program; the difficult part is determining when and how often to measure, where to measure, and how to interpret the measurement once it is made. Regrettably, there are no established rules for dissolved oxygen monitoring programs in aquaculture. The sampling protocol must be based on experience, the needs of the program, and good judgement.

Compromises must often be made between obtaining accurate measurements and the logistical constraints associated with sampling a large number of ponds in a timely manner. These compromises should be made with knowledge of the factors that affect DO concentrations and the ways these factors cause DO concentration to vary over time and from place to place.

Some of the factors to consider when monitoring DO concentrations in ponds (the most common use of oxygen meters in warmwater aquaculture) are discussed below.

Dissolved oxygen monitoring in ponds

Dissolved oxygen concentrations in ponds vary with depth, from one side of a pond to the other, and particularly from one time of day to another. In general, dissolved oxygen concentrations are lowest at dawn and highest at dusk; lowest near the bottom and highest near the surface; and lowest near the upwind side and highest near the downwind side.

A dissolved oxygen measurement applies only to the conditions at the particular location of the measurement, and does not reflect surrounding conditions. A dissolved oxygen measurement also represents a snapshot in time and therefore provides no information about the rates of processes that supply oxygen to the pond (photosynthesis by plants, diffusion from the atmosphere) or the rates of processes that remove oxygen from the pond (respiration by fish, and organisms in the water and mud). The relative rates of these supply and removal processes vary with time and location in ponds and are responsible for the observed variation in dissolved oxygen concentrations. These phenomena and the way they affect the distribution of dissolved oxygen are discussed in any good publication on water quality in aquaculture ponds.

The more intensive the culture system the greater the need for routine water quality monitoring. In ponds with few fish or crustaceans and low inputs of fertilizer or feed, biological activity is slow, even in summer, and phytoplankton blooms are light. Dissolved oxygen concentrations seldom, if ever, reach critically low levels and are relatively consistent with time and location in the pond. As the intensity of culture increases, biological activity increases and phytoplankton become more abundant.

During the summer months, DO concentrations may vary greatly from dawn to dusk, and concentrations may change very quickly. On calm, sunny days, there may be substantial differences in dissolved oxygen concentrations from the surface of the pond to the bottom, even in relatively shallow ponds. Measuring a dissolved oxygen profile from the pond surface to the bottom will indicate the potential risk associated with the mixing, or turnover, of low-oxygen bottom water with high-oxygen surface water.

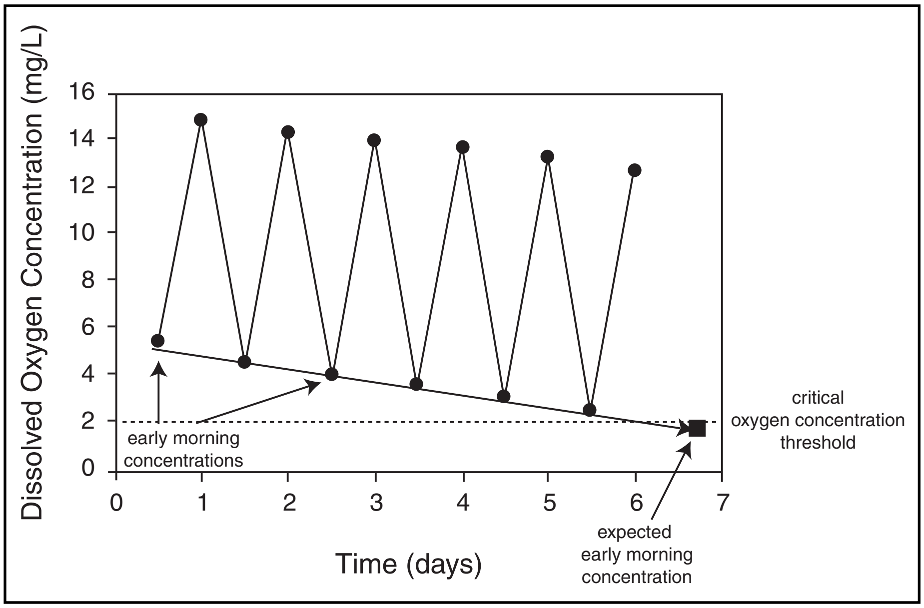

Figure 4. The trend in the dissolved oxygen concentration in a fish pond over several days can help to predict the need for emergency aeration.

In high-density commercial ponds, at least two measurements should be made each day during the growing season. Normal daily extremes can be determined by measuring at dawn and at dusk. During the warm months, critically low dissolved oxygen concentrations usually occur at night, and it may be necessary to sample every hour or two to prevent problems.

On large commercial farms it is often impractical to sample from more than one location in each pond, so management decisions often must be made on the basis of a single sample. This is difficult because it is not possible to select a single point in the pond that represents the average condition, or even the worst-case or best-case condition. Therefore, it is important to always sample each pond at the same location and at the same time of day to minimize variations. If the sampling program is consistent, the behavior of the fish can be correlated to dissolved oxygen concentration, even if the actual concentration where DO is measured has little to do with fish behavior in the pond.

Some consistency can be achieved by sampling every time from the same location in an individual pond and by sampling from the same relative position in all ponds. For example, one might sample from the south side of each pond just for consistency, or from the windward side of each pond to minimize differences caused by changes in wind direction. Pond surface DO concentrations do not reflect “average” or “worst-case” conditions. Therefore, measurements should be made at least 2 feet from the pond bank and 12 to 18 inches beneath the surface. The probe cable can be attached to a pole mounted on a vehicle. Of course, measurements should not be made near aeration devices.

A consistent measurement program allows the farmer to identify "problem" ponds, those in which aeration must begin earlier in the evening than in other ponds. Monitoring DO concentration in the same place at the same time each day also makes it possible to spot trends over several days so that the need for aeration in a particular pond can be anticipated (Fig. 4). Therefore, obtaining an accurate dissolved oxygen measurement may be less important than assessing changes in DO concentration over time and attempting to link it with fish behavior (e.g., reduction in feed consumed, distress).

Caring for dissolved oxygen meters

Most dissolved oxygen meters designed for field use are rugged and can withstand the occasional rough treatment associated with normal use. Most are water-resistant, which means that they can tolerate rainfall, but are not waterproof, which means that they can not tolerate submergence. Water inside the meter will cause an erratic response when making a dissolved oxygen measurement. If a meter is accidentally submerged, open the case and place the meter in a warm, dry location.

A meter that is dropped or jostled excessively may need to be recalibrated. If the meter does not function, have it professionally serviced.

Dissolved oxygen meters are connected to sensors by a cable. The point where the cable enters the sensor may be a weak point. The stress of repeated use can disrupt signal transmission from the sensor to the meter, which is seen as erratic meter response when the sensor is moved in the water. Stress on the junction between cable and sensor can be relieved by forming a loop with the cable near the probe and attaching the cable to the probe body with a cable tie or duct tape.

Changing membranes is probably the most important routine maintenance task that must be performed on dissolved oxygen meters. If there are tears or bubbles beneath the membrane it must be changed.

During heavy use (e.g., summer), the electrolyte solution should be changed monthly. Figure 2 illustrates how to change a membrane on some polarographic sensors. With some practice and skill, a membrane can be changed in less than 2 minutes. Many polarographic dissolved oxygen sensors now use an integral membrane with a plastic cap that screws onto the sensor body. However, integral membrane caps are much more expensive than the traditional membrane/O-ring combination.

The reactions that take place at the electrodes can cause coatings to form; these slow calibration or meter response time. In a polarographic sensor, the gold cathode should be bright yellow and the silver anode should not be tarnished or black. The cathode can be cleaned with emory paper, but the silver anode should be cleaned only by a qualified service representative.

Dissolved oxygen manufacturers

Dissolved oxygen meters can be obtained from the following companies:

Cole Parmer Instrument Company
http://www.coleparmer.com
1-800-323-4340

Corning
http://www.scienceproducts.corning.com/
1-800-492-1110

Danfoss Analytical A/S
http://www.danfoss.com/analytical/
011-45-7488-2222

Extech Instruments Corporation
http://www.extech.com/
1-781-890-7440

Fisher Scientific
https://www1.fishersci.com
1-800-766-7000

Hach Company
http://www.hach.com
1-800-227-4224

Hanna Instruments
http://www.hannainst.com
1-877-694-2662

LaMotte Company
http://www.lamotte.com
1-800-344-3100

Thermo Orion
http://www.thermo.com/eThermo/CDA/BU_Home/BU_Homepage/0,1285,161,00.html
1-800-225-1480

Oxyguard International A/S
http://www.oxyguard.dk/
011-45-4582-2094

Royce Instrument Corporation
http://www.royceinst.com/
1-800-347-3505

YSI Incorporated
http://www.ysi.com
1-800-897-4151

WTW Measurement Systems, Inc.
http://www.wtw-inc.com/
1-941-337-7112

Mention of a specific manufacturer does not imply endorsement by the Southern Regional Aquaculture Center.

The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 00-38500-8992 from the United States Department of Agriculture, Cooperative State Research, Education, and Extension Service.

SRAC Publication No. 191

Southern
Regional
Aquaculture
Center

March 1999

Design and Construction of Degassing Units for Catfish Hatcheries

John A. Hargreaves and Craig S. Tucker*

In some catfish or baitfish hatcheries, water in egg-hatching or fry-rearing tanks may have a condition called “gas supersaturation” that is harmful to fish. Gas supersaturation means that the water contains more gas at a certain air (barometric) pressure and water temperature than would normally occur if the water was allowed to come to equilibrium with the atmosphere. Fish living in such waters may develop a stressful or lethal condition called gas bubble trauma. Gas supersaturation can occur frequently in hatcheries, and small fish confined in shallow tanks are especially susceptible to gas bubble trauma. Because the diffusion of excess gas out of water can be slow, water often must be treated before it is used in a hatchery. Gas supersaturation problems may be difficult to diagnose, but are easily remedied with simple, inexpensive equipment such as the packed-column aerator described here.

Definitions

Nitrogen, oxygen, carbon dioxide, and other atmospheric gases are dissolved to some extent in water. Total dissolved gas pressure is the sum of the partial pressures of all gases dissolved in water. The total amount of gas dissolved in water is commonly expressed as the difference between the sum of the pressure of all gases in water and the sum of the pressure of those same gases in the air (described by the term “ΔP,” which is read as “delta P”). It also can be expressed as the percent saturation of the gases in water. Total dissolved gas pressure, barometric pressure, and P can be expressed in any of the units commonly used to express air pressure, such as millimeters of mercury (mm Hg) or inches of mercury (in Hg).

When the partial pressure of a gas in water is equal to the partial pressure of that gas in air ($\Delta P_i=0$), then that particular gas in the water is at equilibrium with the concentration of the gas in the atmosphere and there is no net movement of that gas either into or out of the water. If the partial pressure of a gas in water is less than the partial pressure of that gas in air (ΔP_i is less than 0), then water is undersaturated with that particular gas and it will diffuse into the water. If the partial pressure of a gas in water is greater than the partial pressure of that gas in air (ΔP_i is greater than 0), then water is supersaturated with that particular gas and it will diffuse out of the water to the atmosphere. It is possible for the total gas pressure in water to exceed barometric pressure (ΔP is greater than 0) while a particular gas is undersaturated.

Total dissolved gas pressure (TGP) is sometimes reported as a percentage of local barometric pressure. At saturation, TGP percent = 100 percent; when waters are undersaturated, TGP percent is less than 100 percent; and if the water is supersaturated, TGP percent is greater than 100 percent.

Table 1. Ways of expressing gas supersaturation.

Condition	ΔP (mm Hg)	TGP (%)	Direction of gas diffusion
Undersaturated	<0	<100	from air into water
Saturated (equilibrium)	0	100	no net diffusion
Supersaturated	>0	>100	from water into air

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*Mississippi State University

Effect of supersaturation on fish

The effect of adding supersaturated water to a hatchery trough or fish tank is similar to opening a soft drink bottle. The pressure that held gases dissolved in water is now released and the gases will form bubbles and diffuse into the atmosphere. If fish are exposed to this water, the gas will diffuse across the gills into the fish. Bubbles can form in the gills, fins, skin and blood. Bubbles in the blood can block circulation and cause serious or fatal injury, particularly to fry or young fish. Some of the symptoms of gas supersaturation include "pop-eye" or hemorrhaging around the eyes, distended stomachs, coagulated yolk in yolk-sac fry, and more importantly, secondary bacterial or fungal infections related to stress. Catfish fry affected by gas supersaturation often become trapped upside down at the surface because bubbles form in the yolk sac.

Identifying gas supersaturation problems

Most problems with supersaturation are first identified when there are unexplained chronic or acute losses of fry in the hatchery. Sometimes the fry will exhibit some characteristic symptom, such as floating upside down or bubbles in the eyes, skin or fins. However, these clinical signs can appear and then disappear rapidly. Often there will be no obvious symptom at all. Gas supersaturation can be suspected if tiny bubbles form on the insides of the hatchery tanks. Running your hand over the inside of a tank will release a swarm of these small bubbles and make them easier to see.

The ΔP of a hatchery water supply can be measured with a saturometer. Most hatchery managers do not have this rather specialized and expensive piece of equipment, and it is not an essential tool. Some government fisheries biologists or university researchers have access to a saturometer, so if you suspect a problem, you may be able to find someone who can visit the hatchery and make the measurement to confirm whether or not a problem exists. Note, however, that the severity of a gas supersaturation problem in a hatchery can change over time, sometimes suddenly, depending upon the water pumping rate and the condition of the plumbing in the hatchery. Fry should be observed vigilantly for potential gas bubble problems.

Sources of gas supersaturation

If you determine that the water in hatchery rearing tanks is supersaturated, it is important to identify the source of the supersaturated water. The most effective approach to solving the problem depends on the origin of the gas. The water source itself may be supersaturated, or the water may become supersaturated as it is pumped to the hatchery.

Supersaturation is usually not a problem in good quality surface waters, although other problems with using surface waters in hatcheries outweigh that small advantage (see SRAC Publication 461). Surface waters with dense growths of aquatic plants or algae can become supersaturated with dissolved oxygen on bright, sunny afternoons.

Most catfish hatcheries use deep groundwaters because the supply is consistently of high quality. Water from deep wells is warmed by the heat of the earth, making it unnecessary to heat the water to the optimum temperature for egg and fry incubation. However, groundwater often is supersaturated with dissolved gases. If that is the case, and there is no alternative water source for the hatchery, the water can be "degassed" and aerated in a packed-column aerator as described below.

Although not a common problem, especially when wells are properly constructed, waters can become supersaturated if air is sucked into the water supply when the well "surges." Surging occurs when sands dislodged during well drilling partially clog the screen or strainer at the bottom of the well casing. This impedes the flow of water into the casing, which results in water being pumped out of the well faster than it flows into the casing from the aquifer. When the water level inside the casing drops below the bottom of the intake pipe strainer, air is sucked into the line and gases are forced into solution as water passes through the pump. This problem is most common in new wells and usually corrects itself as the well is used. If surging persists, inform the person who drilled the well. Screens of older wells in areas with hard, alkaline groundwaters may become clogged by encrustations of lime or iron oxide. Cleaning with muriatic (dilute hydrochloric) acid will correct this problem and most well-drillers do this routinely.

Regardless of the water source and whether or not it starts out supersaturated, faulty plumbing of the water supply lines to the hatchery can cause it to become supersaturated (or more supersaturated). This occurs when air is sucked into the water through small, "pin-hole" leaks in the plumbing fittings and pipes on the suction side of pumps. As the entrained air passes through the pump, it is pressurized and some of the gases are driven into solution. More gas entrainment can occur on the pressure (outlet) side of a pump, particularly across a partially-open, true-union, PVC ball valve.

Problems caused by faulty plumbing can sometimes be remedied by finding the leak and repairing the line, although it is best to avoid or prevent the problem in the first place. When constructing the hatchery, pay particular attention to proper application of adhesives at plumbing joints and fittings. Clean fittings carefully with an approved solvent and generously apply adhesive to both pipe and fitting before joining with a quarter twist of pipe against fitting. Apply teflon tape or pipe compound liberally to the threads of reducer bushings or other threaded fittings, particularly at the pump inlet and outlet.

When catfish hatcheries are supplied with water from a well, diagnosing the source of the supersaturation is usually not difficult because most groundwaters in the Southeast do not contain dissolved oxygen. If the water flowing into the hatchery contains no dissolved oxygen but is nevertheless supersaturated with gas, the groundwater itself probably is supersaturated or has become supersaturated when heated in a closed boiler. If, however, the water flowing into the hatchery contains some dissolved oxygen (often just 1 or 2 mg/L), that means that the water has contacted air at some point and the problem is caused by an air leak in the plumbing or a surging well. Quite often, air bubbles entrained in the water by these two processes makes a hissing sound as the water travels along the piping. This sound is often most noticeable at elbows or “T” fittings.

Problems caused by an air leak in the plumbing can be differentiated from those caused by a surging well by turning the well off for an hour or two, and then turning it on while measuring the dissolved oxygen concentration of the water as it flows into the hatchery. If the problem is caused by an air leak in the supply line, dissolved oxygen will be detected in the water almost immediately after the well is turned on. If the problem is caused by a surging well, the water will not contain dissolved oxygen at first because anaerobic groundwater is being pumped into the hatchery. If, after some period of pumping, the water level inside the casing falls below the intake and air is sucked in, the dissolved oxygen level in the water will suddenly begin to rise, indicating a surging well. The time interval between turning the well on and the first surging depends on the well pumping capacity and the degree to which the screen is clogged; it can range from a few minutes to several hours.

Waters also can become supersaturated when heated in a closed boiler where excess gases can not escape completely. This occurs because the solubility of gases decreases with increasing temperature, so if gases cannot escape when water is heated, the water will be supersaturated at the final temperature. This occurs often in hatcheries that use cool groundwaters or surface waters early in the spring spawning season. Heating water from 20° C (68° F) to 26° C (80° F) in a closed boiler can cause an increase in ΔP sufficient to cause chronic gas bubble trauma in channel catfish sac-fry.

Packed column design

Some problems with gas supersaturation can be avoided by properly plumbing the water supply line to the hatchery and by using good well drilling and maintenance practices. Water flowing into hatchery tanks can be partially degassed by vigorously aerating the holding tank with a number of diffusers or with an agitator, although these techniques are not very efficient and not completely effective. Water can also be degassed somewhat by breaking the flow into a fine spray with a common garden-hose spray nozzle and spraying water into the hatching or rearing tank. However, one of the simplest and most effective ways to manage gas supersaturation problems is to use packed-column aerators.

Packed columns serve two roles, depending upon the quality of incoming water. If the water is supersaturated with dissolved gases, then a properly designed and constructed packed column will relieve the supersaturated condition. If the dissolved oxygen concentration of the water is low, and usually dissolved oxygen is absent in groundwater, then a properly designed and constructed packed column will also saturate the water with dissolved oxygen.

A packed column consists of a vertical vessel filled with packing medium. The medium should have a large (about 90 percent) void or empty space per unit volume and should pack in a way that allows the water flow to break up randomly into a thin film that trickles down through the column, following a very circuitous pathway. Various packing media are sold under the names ballast rings, Bio-barrels®, Actifil® pall rings, Tri-pack® spheres, and Nor-Pac®. A perforated support plate holds the medium in at the bottom of the column. Near the top of the column, a water distribution plate with many holes is placed over the packing medium.

The height of the packing is an important design variable of a packed column. Packing height is based on a number of design criteria and will depend upon the characteristics of the incoming water. Two cases are presented below to illustrate how to configure the packed column.

In the first case, assume that the water contains no dissolved oxygen but is not supersaturated. The packed column will be used only as an aerator and Figure 1 can be used to estimate the height of the packed column required to provide the desired dissolved oxygen concentration at the outlet. To use

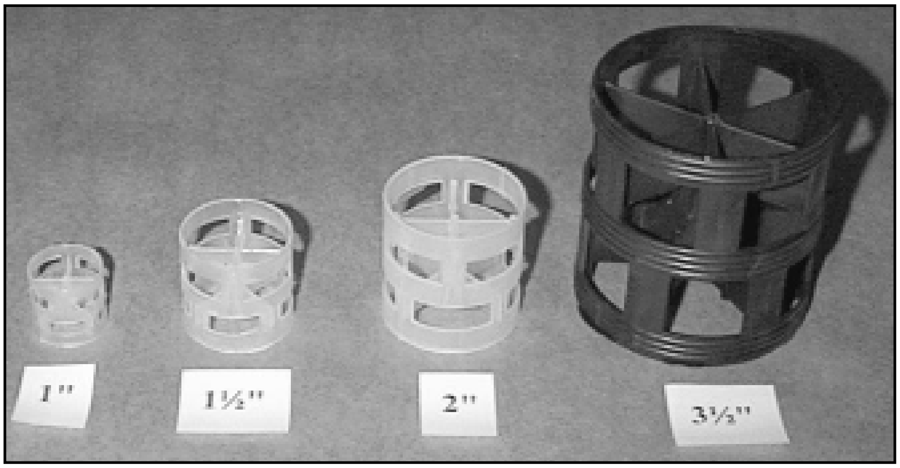

Figure 1. Pall rings of various sizes can be used as media in packed columns.

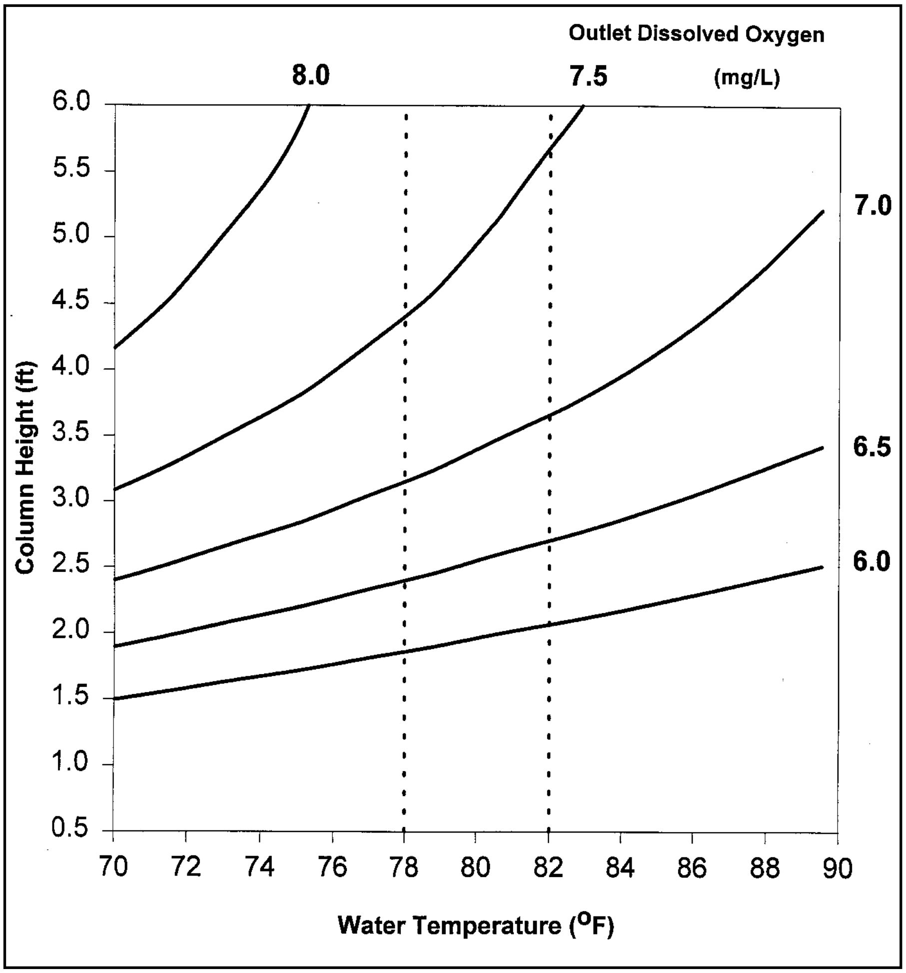

Figure 2. Packed column height required to result in various outlet water dissolved oxygen concentrations at a range of water temperatures. Area within dashed lines indicates the optimum temperatures for channel catfish egg incubation.

the figure for design purposes, begin by selecting the water temperature. Extend a vertical line up to the desired dissolved oxygen concentration. Then, extend another line horizontally to the left, at a right angle to the first line, to select the packing height. For example, if the temperature of a catfish hatchery water supply is between the optimum of 78 and 82° F and the desired dissolved oxygen concentration of the water flowing out of the packed column is 90 percent of saturation (between 7.0 and 7.3 mg/L), then a packing height of 3.5 to 4 feet is necessary. As water temperature increases, the packing height required to achieve a given dissolved oxygen concentration increases, although the packing height required to achieve 90 percent saturation is not affected by temperature and stays at about 3 feet 8 inches.

In the second case, assume that the water is supersaturated with dissolved gases. Use Figure 2 to estimate the required packing height for the desired gas pressure differential (ΔP) between the outlet water and the atmosphere. Most hatchery waters should have a ΔP between 10 and 20 mm Hg and should not exceed 40 mm Hg. From the figure, it can be seen that as the ΔP of the incoming water increases, the packing height required to produce a given ΔP of the outlet water increases. The lower the desired ΔP of the outlet water, the greater the packing height required. The vertical dashed line on the figure provides a point of reference by indicating the average ΔP of well water from 27 catfish hatcheries in the Mississippi Delta. But remember, the ΔP of well waters can change through time and may suddenly become a severe problem. To use the figure for design purposes, begin by selecting the ΔP of the incoming water. Extend a vertical line up to the desired outlet ΔP. Then, extend another line horizontally to the left at right angles to the first line to select the packing height. As an example, if the ΔP of incoming well water is about average for catfish hatcheries in the Mississippi Delta, and the desired outlet ΔP is about 10

Table 2. Guidelines for selecting packed column diameter, size of medium, and air flow rate based on water flow rates.

Recommended flow rate (gpm)	Maximum flow rate (gpm)	Column diameter (inches)	Media size (inches)	Air flow rate (cfm)	"Squirrelcage" blower size (amps)
15	20	8	1	6	0.2-0.3
35	50	10	1	14	0.2-0.3
70	100	12	1.5	28	0.4
125	150	16	1.5	50	0.5
150	250	18	2	60	0.6
250	450	24	2	100	0.7
450	700	30	3.5	180	2.1

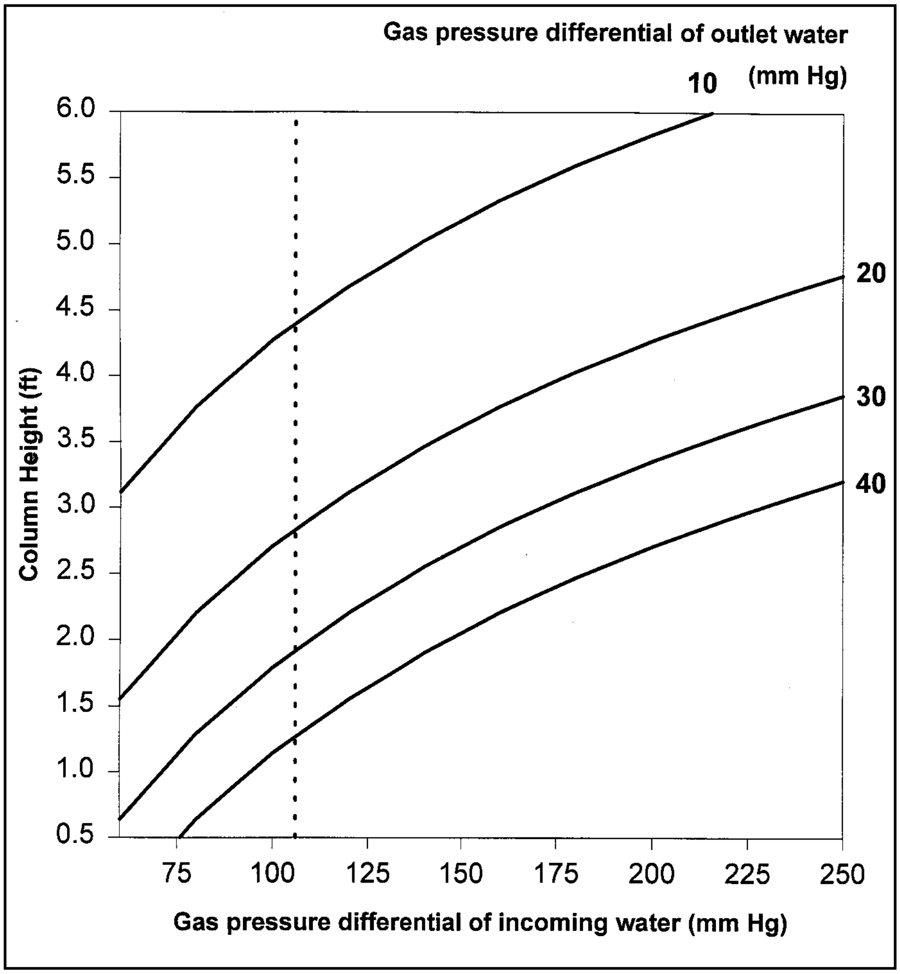

Figure 3. Packed column height required to result in various outlet water gas pressure differentials as a function of incoming water gas pressure differential. Dashed line indicates average gas pressure differential in groundwaters used in catfish hatcheries in the Mississippi Delta.

mm Hg, then the required packing height is 4 to 4.5 feet. Such a column height will also achieve at least 90 percent saturation of water with dissolved oxygen.

In both design cases, an additional 1.5 to 2 feet should be added to the column height to accommodate inlet and outlet plumbing adjacent to water distribution and media support plates.

The required diameter of a packed column will depend on water flow rate (Table 2). Flow rates to packed columns range from 40 to 100 gpm/ft^2 of column cross-sectional area. Table 2 offers some guidelines on the selection of appropriate column diameters. Most catfish hatcheries require a water flow of 100 to 150 gpm, and so will require columns 12 to 18 inches in diameter. Flow rate should not exceed the design maximum, as this will flood the column and prevent degassing. Also avoid using columns with diameters smaller than 6 inches because of potential problems with short-circuiting water flow down column walls.

One of the most important, and often neglected, design parameters of packed columns is air flow rate. Good air flow is essential for effective performance. Air flow provides oxygen and strips away undesirable dissolved gases such as carbon dioxide, hydrogen sulfide and methane. If the top and bottom of the column are open to the air, then air flow through the column should be sufficient to degas the water. In such a case, add 2 additional feet to the packing depth as determined by Figures 2 and 3. However, if the bottom of a packed column is placed in a sump or is sealed, then forced-air ventilation is necessary.

The principal behind a packed column is to break water up into thin layers, across which gas can transfer efficiently. This process is enhanced by passing a relatively large volume of air through the column in the opposite direction (counter current) to the water flow. At least 2 to 3 unit volumes of air should be added to the column for each unit volume of water (Table 2). “Squirrel-cage” blowers or regenerative blowers can be used for this purpose, but “squirrel-cage” blowers are a better choice because they are designed to deliver air against a very low pressure gradient, typical of packed columns, whereas regenerative blowers are designed to move air against a fairly low head pressure of water (typically 24 to 48 inches). Counter current air flow requires that the lower end of the packed column be sealed or submerged in a water collection sump or else the air will flow out of the column in the same direction as the water. It also requires an air ventilation riser pipe through the water distribution plate near the top of the column.

Packed column construction

Once column height, column diameter, medium size and blower size have been selected, the packed column can be constructed. Columns are generally cylindrical in shape; therefore, PVC pipe, concrete culverts, and lined grain silo rings are suitable materials for construction. Materials less than $^1/_8$ inch thick can be used for packed columns. Packed columns can be integrated with water supply head tanks or built as “stand-alone” units.

The advantage of integrating the packed column with an exterior head tank is that water flow to the hatchery can be regulated by the head pressure of water in the tank. However, water must then be pumped to some relatively small additional head to account for the packed column height.

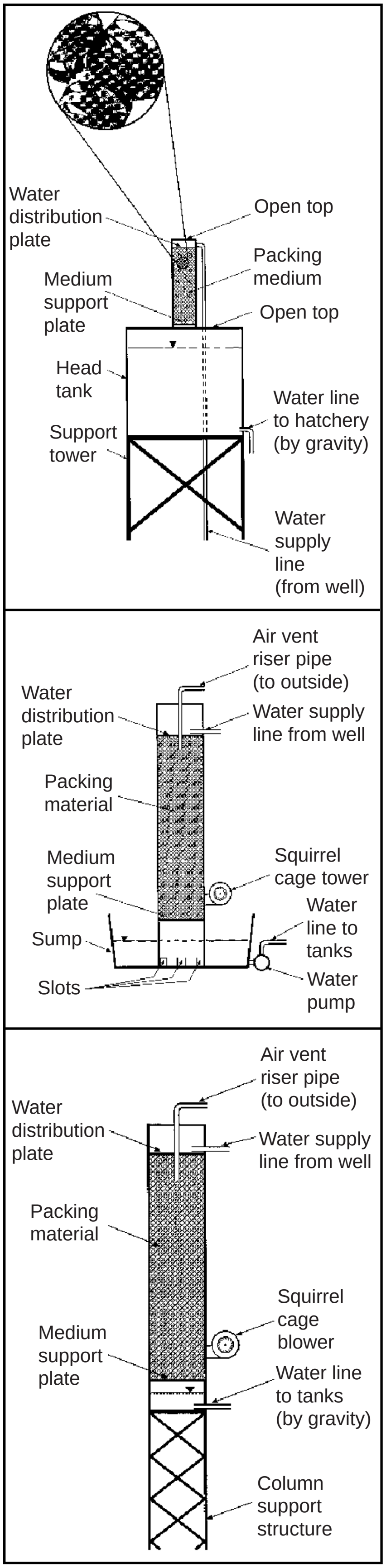

Figure 4. Components and suggested configurations of packed columns for channel catfish hatcheries.

Ventilation of packed columns integrated with head tanks is probably not necessary, as the top and bottom of the column are open. The major disadvantage of integrating a packed column with a head tank is the relatively large heat loss that may occur across the packed column, particularly when operated early in the hatchery season. A large heat loss as water passes through the packed column might necessitate reheating the water in a boiler, which may defeat the purpose of using the packed column because heating the water may itself cause supersaturation.

Stand-alone units can be placed within the hatchery building, but this configuration may require that water be pumped a second time, usually from a collection sump placed at the base of the column. If a packed column is placed within a water collection sump, then the column must be mounted in such a way that the packing medium is not flooded. This can be accomplished by physically mounting the column above the water level or, if the base of the column rests on the sump bottom, by placing the medium retention plate at a height in the column above the water level of the sump. When a stand-alone packed column is placed within a hatchery the building must be ventilated or the air flow from the column vented to the outside so that carbon dioxide and other harmful gases will not accumulate.

To construct a packed column, first suspend the medium support plate in the column. If the column is a stand-alone unit, locate the support plate at least 3 to 6 inches above the water level of the collection sump. Vinyl-coated hardware cloth or perforated aluminum sheet metal are suitable materials for support plate construction. The support plate in larger diameter columns may be supported by extending re-enforcing rods (“re-bar”) or other rolling stock through the column and sealing the holes with silicone caulk. Or, blocks or a ring for holding the support plate can be attached to the inner diameter of the column.

Next, cut a square hole, corresponding to the outlet from the squirrel-cage blower, near the lower end of the column. The blower should be mounted well above the water level of the sump to minimize the potential for electrical shock and flooding of the blower motor. The blower can be mounted on the column just before installation or right after the column is installed.

Construct the water distribution plate and place it about 6 to 9 inches from the top of the column. This allows space for water to splash before passing through the plate. The water distribution plate does not need to be as rigid as the medium support plate, although it should be about $^{3}/_{16}$ inch thick. Suitable materials include perforated aluminum sheet metal, plexiglass, or fiberglass-reinforced plastic. The support plate should be drilled with holes, as suggested in Table 3, with a hole in the center large enough for a riser pipe (2- to 4-inch ID depending upon column diameter) that vents the air introduced by the blower at the bottom of the column. If flow rate is expected to vary predictably (for example, increasing during the hatchery season), then multiple and interchangeable water distribution plates can be fabricated.

Before placing the water distribution plate in the column, add the packing medium. Add small amounts at a time and shake the column or use a stick or piece of pipe to stir the medium so it will pack well. Once the medium is packed into the column, place the water distribution plate on the plate support structure. Sealing the support plate to the column wall with a bead of caulk helps direct water flow through the column rather than down the wall.

The inflow pipe can be placed over the top of the distribution plate, or water can be introduced from the side, through the wall of

Table 3. Guidelines for constructing a water distribution plate for a packed column of a given diameter.

Column diameter (inches)	Air vent riser pipe diameter (inches)	Hole diameter (inches)	Number of holes at recommended flow rate	Number of holes at maximum flow rate
8	2	1/4	35	50
10	2	1/4	50	60
12	2	3/8	40	60
16	3	3/8	70	80
18	3	3/8	80	140
24	4	1/2	80	140
30	4	5/8	90	140

the packed column. The top of the column can be open or fitted with a cover that can also hold the water supply plumbing in place.

A packed column requires very little regular maintenance. Many groundwaters contain fairly high concentrations of dissolved iron, which can oxidize and settle out on the medium as a rust-colored solid. It is highly unlikely that enough oxidized iron will settle out to clog the medium. Rust-colored solids passing through the packed column can be removed by directing the water flow through a settling tank, gravel bed, or sand filter. It is good practice to inspect the column between hatchery seasons and, if necessary, remove the medium and dislodge any accumulated solids with high-pressure water. The medium also can be removed and placed in a solution of muriatic acid for cleaning, but should be thoroughly rinsed with fresh water before it is used again.

Acknowledgments

John Colt and Barnaby Watten provided helpful suggestions for this fact sheet.

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The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 94-38500-0045 from the United States Department of Agriculture, Cooperative States Research, Education, and Extension Service.

SRAC Publication No. 468

Southern
Regional
Aquaculture
Center

April 1996

Carbon Dioxide in Fish Ponds

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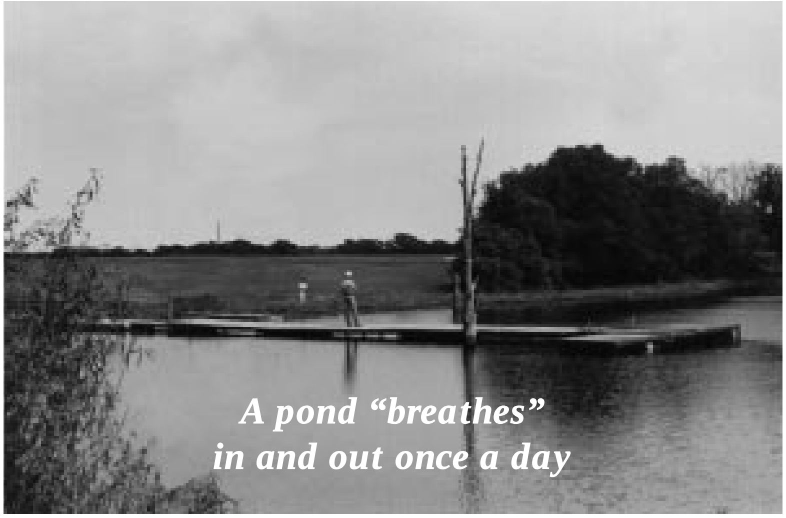

A pond “breathes” in and out once a day

The primary sources of carbon dioxide in fish ponds are derived from respiration by fish and the microscopic plants and animals that comprise the fish pond biota. Decomposition of organic matter is also a major source of carbon dioxide in fish ponds. While producers are rightly concerned with maintaining adequate concentrations of dissolved oxygen, knowledge of the “flip-side” of the oxygen equation is also important.

Fish ponds can be thought of as “breathing” over a 24-hour period. During the day, when the sun is shining brightly, oxygen is supplied to the pond by photosynthesis of algae and other aquatic plants (the “inhale”). During the night, photosynthesis ceases, and the algae, sediment and fish consume oxygen (the “exhale”), producing the characteristic fluctuating pattern of dissolved oxygen concentration well known to fish farmers. The daily pattern of carbon dioxide concentration is generally opposite that of dissolved oxygen (Figure 1). During the day, algae take up or “fix” carbon dioxide that is free in the water and carbon dioxide concentration is therefore lowest (often 0 mg/L) during late afternoon, when dissolved oxygen is highest. During the night, the respiration of pond organisms produces carbon dioxide, which accumulates to a maximum (usually around 10 to 15 mg/L) at dawn.

The problem with the potential toxicity of carbon dioxide can be related to the daily fluctuating pattern of dissolved oxygen and carbon dioxide concentrations. Carbon dioxide concentrations are highest when dissolved oxygen concentrations are lowest. Thus, dawn is a critical time for evaluating pond water quality from the standpoint of both dissolved oxygen and, to a lesser extent, carbon dioxide. In addition, there is some evidence to suggest that the toxicity of carbon dioxide is enhanced by low dissolved oxygen concentrations. Fish are able to rid themselves of carbon dioxide through the gills in response to a difference in carbon dioxide concentration between fish blood and the surrounding water. If environmental carbon dioxide concentrations are high, the fish will have difficulty reducing internal carbon dioxide concentrations, resulting in accumulation in fish blood. This accumulation inhibits the ability of hemoglobin, the oxygen-carrying molecule in fish blood, to bind oxygen, and may cause the fish to feel stress similar to suffocation.

The density of the algae bloom has an important effect on the magnitude of daily fluctuations of oxygen and carbon dioxide.

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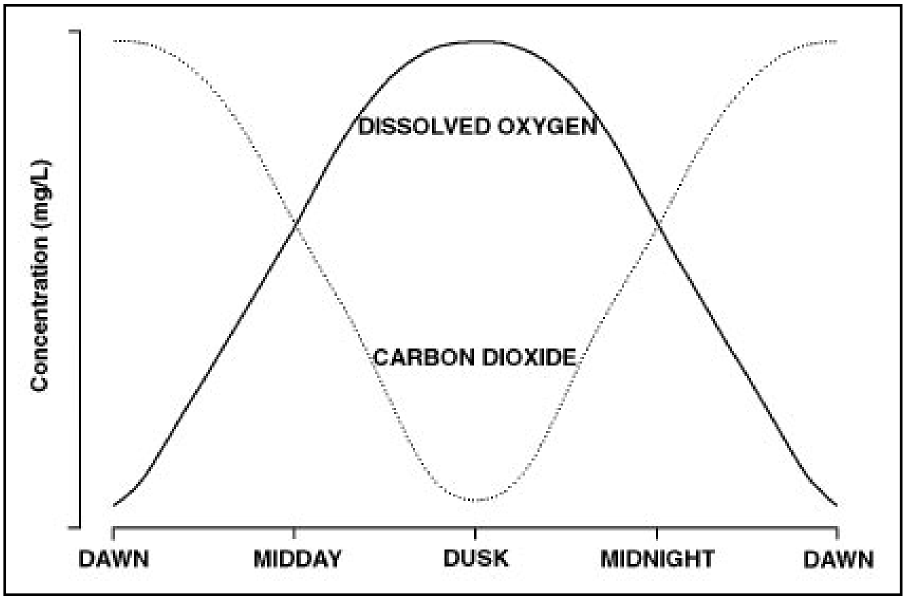

Figure 1. The daily cycle of oxygen and carbon dioxide in a fish pond.

Oxygen and carbon dioxide concentrations in ponds with a light algae bloom will not fluctuate very much between early morning and late afternoon, analogous to "shallow breathing." In ponds with a thick, dense algae bloom, fluctuations are more extreme, analogous to "deep breathing." Carbon dioxide problems are therefore more likely as the thickness of the bloom increases.

Carbon dioxide problems most likely in summer

Over an annual cycle, carbon dioxide concentrations are maximum during winter and minimum during summer. However, carbon dioxide is rarely a problem in winter because dissolved oxygen concentrations are usually well above saturation levels. Occasionally during the winter fish may appear to swim listlessly near the surface as if they were "under the influence," possibly due to elevated carbon dioxide levels. Such a condition may arise after a period of extremely calm and cloudy weather, but quickly passes once sunny or windy weather returns.

Summer is the time of year when carbon dioxide is most likely to be a problem in fish ponds. Warm water temperatures increase the metabolism of all pond organisms and therefore respiration rates are high. It is also a time of year when feeding rates are high. The decomposition of wastes generated by large quantities of organic matter added to fish ponds in the summer requires large quantities of dissolved oxygen and produces large quantities of carbon dioxide. During the summer, carbon dioxide concentrations are lower than during winter, but dissolved oxygen concentrations are often critically low. Fortunately, summer is also the time of year when ponds are aerated frequently. In addition to supplying critical dissolved oxygen, vigorous aeration will drive off some proportion of the carbon dioxide produced in the pond.

Measure pH to estimate carbon dioxide

Carbon dioxide can be measured directly with standard test kits. Alternatively, measurement of pH can be used to estimate carbon dioxide concentration because carbon dioxide acts as an acid in water. As carbon dioxide is added during the night, pH will decline. (Conversely, when carbon dioxide is removed during the day, pH will increase.) There are important interrelationships between carbon dioxide, pH and total alkalinity. Knowing pH and total alkalinity will allow the estimation of carbon dioxide. Estimation of carbon dioxide by pH measurements is plagued by difficulty in obtaining an accurate pH measurement. Litmus paper, drop counting test kits, and various probes with meters have been used with varying success. The selection of measurement devices for pH is largely a situation in which "you get what you pay for." For example, pH pens are inaccurate, particularly if not calibrated correctly, and do not compensate for changes in temperature. Some scientific supply houses now sell narrow-range litmus paper which allows for low-cost, rapid estimation of pH.

Graphical estimation technique is easy

A simple graphical technique for estimating carbon dioxide concentration is presented in Figure 2.

The first step is to determine the total alkalinity of the pond water using a standard test kit. Next, determine the pH from a water sample collected without splashing or bubbles. Draw a straight line up from the pH value to the curved line representing the total alkalinity value closest to that of the pond (Step 1). Now extend another straight line to the left-hand axis, indicating the free carbon dioxide concentration (Step 2). The straight line extending across from 20 mg/L represents a "critical" concentration, above which carbon dioxide may be a problem. Therefore, using the chart, a set of "critical" pH values can be determined for ponds with different total alkalinity (Table 1). In general, water can hold more carbon dioxide as temperature declines, although differences in temperature are less important than differences in total alkalinity and thus, for practical purposes, application of some kind of temperature correction is not necessary for estimation of carbon diox-

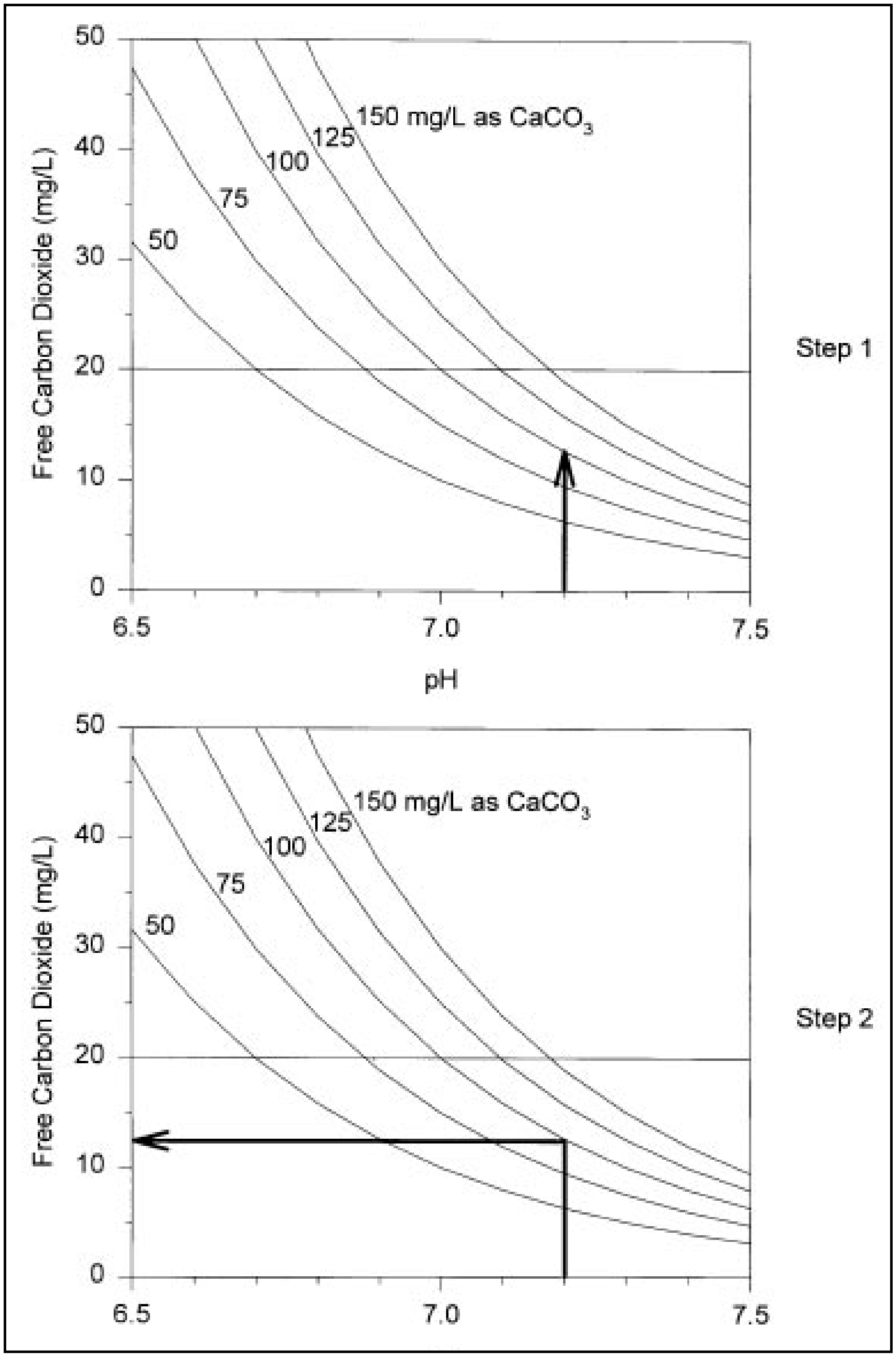

Figure 2. A graphical technique for estimation of carbon dioxide concentration.

Table 1. Critical pH values at a given level of alkalinity.

Total alkalinity (mg/L as CaCO3)	Carbon dioxide may be a problem at a pH value less than:
50	6.7
75	6.9
100	7.0
125	7.1
150	7.2

ide. Figure 4 on page 6 is a blank graph that can be photocopied and used on the farm.

The graphic and the table indicate that carbon dioxide is more likely to be a problem as alkalinity increases. However, alkalinity provides "buffering capacity" to pH changes caused by carbon dioxide and pH is therefore unlikely to fall to such critical levels. The pH of most ponds at dawn is usually between 7.5-8. Carbon dioxide in ponds with low alkalinity (20 to 50 mg/L as $CaCO_3$) may cause the pH to fall to the lower limits of the range for optimum fish growth and production.

The potential for carbon dioxide problems can be evaluated by a simple, "quick-and-dirty" method. Collect a bucket of water and measure the pH. Put an airstone in the bucket and run air through the water for about 30 minutes. If the pH increases by more than one pH unit, then carbon dioxide may be a problem.

Carbon dioxide is an unusual problem in fish ponds

In general terms, carbon dioxide is rarely a cause for concern in fish ponds with sufficient alkalinity. There are a few specific circumstances or scenarios in which carbon dioxide may be a problem, such as the period following the crash of an algae bloom or the application of an algicide, such as copper sulfate. Large quantities of organic material derived from dead plankton are quickly decomposed, reducing oxygen and increasing carbon dioxide. Again, emergency aeration practices serve the dual role of supplying oxygen and reducing carbon dioxide.

Under certain circumstances, carbon dioxide can be a problem in ponds deeper than 4 or 5 feet, such as in so-called combined watershed/levee ponds. Deep ponds may "stratify" or develop layers of relatively lighter, warmer, oxygen-rich water overlaying layers of relatively more dense, cooler, stagnant (and carbon dioxide rich!) water. In ponds that have not been aerated or mixed for several weeks during warm and relatively calm weather, strong sustained winds or vigorous aeration can cause ponds to “roll over” and mix deep water with surface water, thereby increasing carbon dioxide concentration throughout the water column. During the summer, when carbon dioxide is most likely to be a problem, ponds are typically aerated through the night. Although deep ponds may stratify and destratify daily, water currents established by aeration and wind blowing over the water surface usually keep the water column well-mixed and, as a result, carbon dioxide problems rarely occur.

Carbon dioxide may accumulate when fish are held at high density, such as in live-cars, hauling tanks or crowded in front of aerators during low oxygen episodes. Even though carbon dioxide levels may rise dramatically, the problem can usually be alleviated by aeration, which adds oxygen while driving off some carbon dioxide.

Chemical treatment is a temporary solution

Carbon dioxide can be removed by chemical treatment of pond water with liming agents such as quicklime, hydrated lime or sodium carbonate (Table 2). These liming agents chemically react directly with carbon dioxide, resulting in reduced carbon dioxide and increased alkalinity and pH. Agricultural lime will not chemically remove carbon dioxide from pond waters.

In order to calculate the amount of a particular liming agent to apply to a pond, the following generalized formula can be used. Alternatively, consult Figure 3 for a quick, graphical estimation of quicklime treatment requirements for a given pond size.

factor from table
x carbon dioxide concentration (mg/L)
x pond area (acres)
x average depth (ft)
= pounds of liming agent to add

For example, the amount of hydrated lime required to treat a 10-acre pond with an average depth of 4 feet and a carbon dioxide concentration of 20 mg/L is 3.45 x 20 x 10 x 4 = 2,760 pounds or approximately 1.4 tons. Treatment of the same pond with sodium carbonate would require 5,184 pounds or 2.6 tons. Clearly, large quantities of liming materials are required to chemically treat a carbon dioxide problem.

Table 2. Liming agents able to remove carbon dioxide from pond waters.

Liming Agent	Chemical formula	Factor	Comments
Quicklime	CaO	3.45	-caustic (protect skin and eyes) -potential for high pH -relatively low solubility
Hydrated lime	$Ca(OH)_2$	4.57	-caustic (protect skin and eyes) -potential for high pH -relatively low solubility -relatively inexpensive
Sodium carbonate	Na_2CO_3	6.48	-safe -low potential for high pH -relatively high solubility -quick reaction with carbon dioxide

At best, treatment with liming agents represents a temporary solution. Once carbon dioxide is consumed by reaction with liming agents, additional carbon dioxide may accumulate because treatment of ponds with liming agents does not address the root cause of a presumed carbon dioxide problem. In ponds receiving feed at very high rates (>100 lbs/acre per day) or in which rapid decomposition occurs following an algae crash, treatment with a liming agent does not affect the rate of carbon dioxide production and thus represents a temporary, “band-aid” solution.

Perhaps a more serious consequence of chemical treatment of carbon dioxide problems is related to pH, which may exceed 10 in poorly buffered (low alkalinity) waters following treatment with certain liming agents (such as quicklime and hydrated lime). High pH causes a shift towards a greater proportion of the more toxic form of ammonia. Consequently, a well intended application of certain liming agents to “treat” what is thought to be a carbon dioxide problem can result in a very stressful environment for fish.

The bottom line

Application of chemicals to treat a carbon dioxide “problem” is likely to be of limited, temporary benefit. Aeration and mixing are the most effective available mechanical methods for the management of carbon dioxide and dissolved oxygen. Vigorous aeration accelerates the diffusion of carbon dioxide out of water and

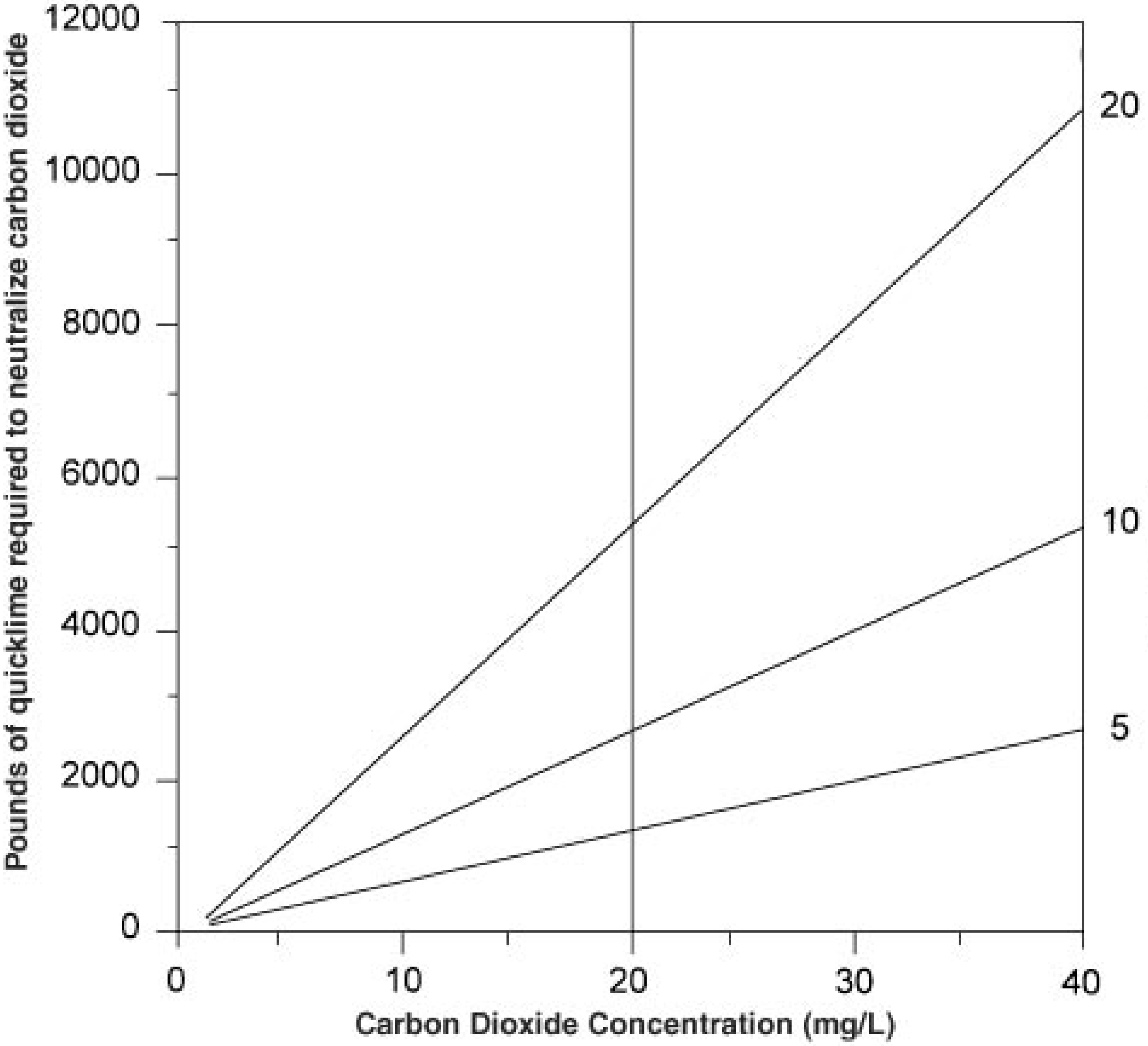

Figure 3. A graphical technique for estimation of quicklime required to neutralize carbon dioxide.

mixing will prevent or minimize the establishment of a carbon dioxide-rich layer of water near the pond bottom. Maintaining a moderate plankton density (Secchi disk visibility between 6-12”) will maximize the biological uptake of carbon dioxide.

A clear determination of a carbon dioxide problem is required prior to any treatment. If a carbon dioxide problem is suspected, other water quality variables (particularly dissolved oxygen and ammonia) should be evaluated before attempting any treatment.

The toxicity of carbon dioxide increases as dissolved oxygen concentration declines. Often, the problem can be traced to something other than carbon dioxide.

The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 94-38500-0045 from the United States Department of Agriculture.

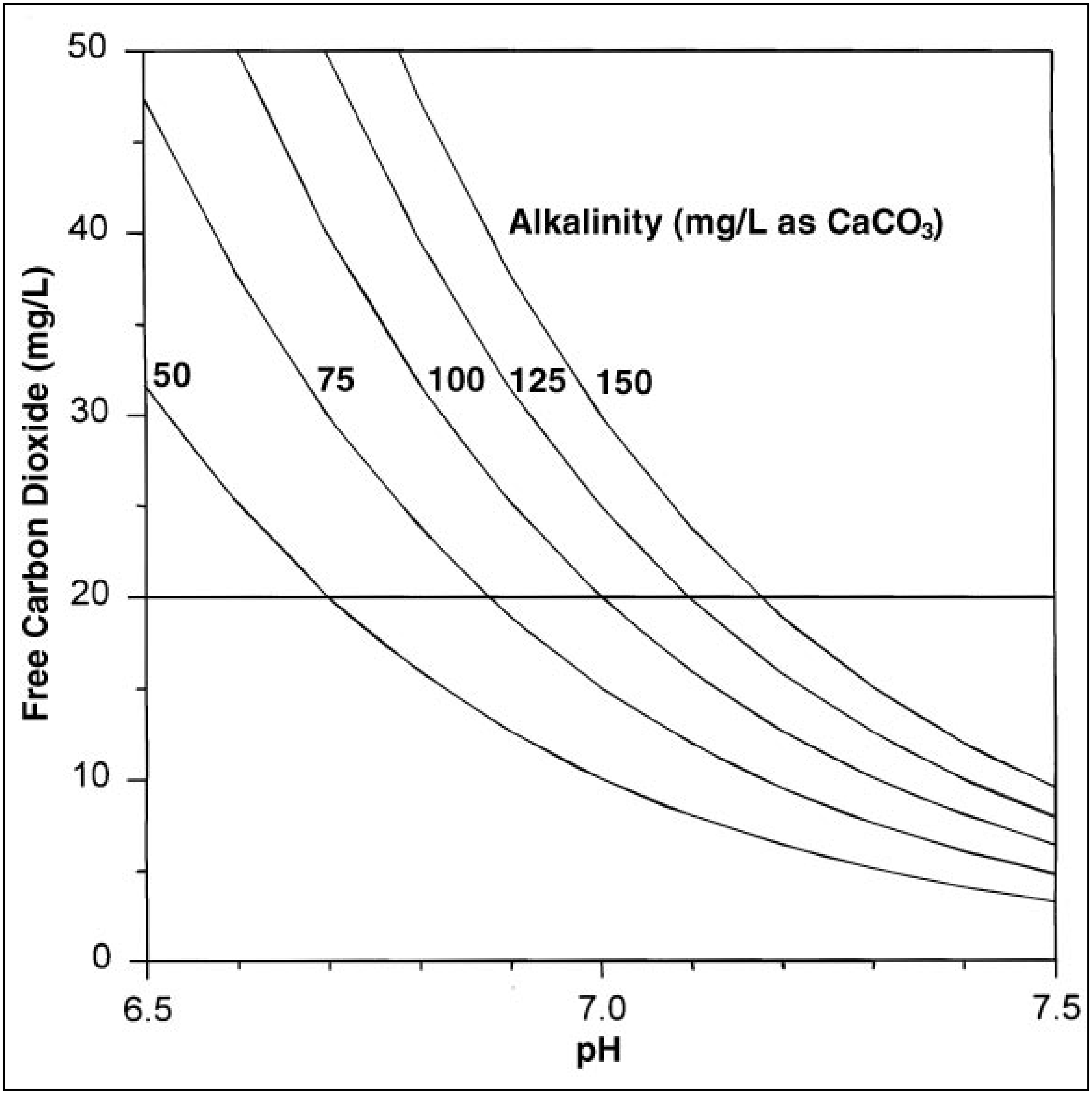

Figure 4. Blank graph for use by pond managers.

SRAC Publication No. 464

Southern
Regional
Aquaculture
Center

December 1992

Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds

William A. Wurts and Robert M. Durborow*

Water quality in fish ponds is affected by the interactions of several chemical components. Carbon dioxide, pH, alkalinity and hardness are interrelated and can have profound effects on pond productivity, the level of stress and fish health, oxygen availability and the toxicity of ammonia as well as that of certain metals. Most features of water quality are not constant. Carbon dioxide and pH concentrations fluctuate or cycle daily. Alkalinity and hardness are relatively stable but can change over time, usually weeks to months, depending on the pH or mineral content of watershed and bottom soils.

pH and carbon dioxide

The measure which indicates whether water is acidic or basic is known as pH. More precisely, pH indicates the hydrogen ion concentration in water and is defined as the negative logarithm of the molar hydrogen ion concentration (-log [H+]). Water is considered acidic when pH is below 7 and basic when pH is above 7. Most pH values encountered fall between 0 and 14. The recommended pH range for aquaculture is 6.5 to 9.0 (Figure 1).

Fish and other vertebrates have an average blood pH of 7.4. Fish blood comes into close contact with water (1- or 2-cell separation) as it passes through the blood vessels of the gills and skin. A desirable range for pond water pH would be close to that of fish blood (i.e., 7.0 to 8.0). Fish may become stressed and die if the pH drops below 5 (e.g., acidic runoff) or rises above 10 (e.g., low alkalinity combined with intense photosynthesis by dense algal blooms – phytoplankton or filamentous algae).

Pond pH varies throughout the day due to respiration and photosynthesis. After sunset, dissolved oxygen (DO) concentrations decline as photosynthesis stops and all plants and animals in the pond consume oxygen (respiration). In heavily stocked fish ponds, carbon dioxide (CO_2) concentrations can become high as a result of respiration. The free CO_2 released during respiration reacts with water, producing carbonic acid (H_2CO_3), and pH is lowered.

$$H_2O + CO_2 = H_2CO_3 = H^+ + HCO_3^-$$

Table 1 summarizes the relative changes in dissolved oxygen, CO_2 and pH over 24 hours.

Carbon dioxide rarely causes direct toxicity to fish. However, high concentrations lower pond pH and limit the capacity of fish blood to carry oxygen by lowering blood pH at the gills. At a given dissolved oxygen concentration (e.g., 2 mg/L, milligrams per liter; same as parts per million, ppm), fish may suffocate when CO_2 levels are high and appear unaffected when CO_2 is low. Catfish can tolerate 20 to 30 mg/L CO_2 if accumulation is slow and dissolved

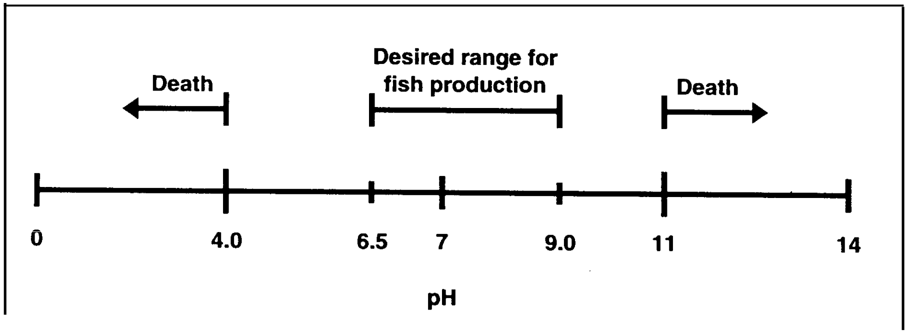

Figure 1. pH scale showing recommended range.

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* Kentucky State University

Table 1. Relative concentration changes for dissolved oxygen, carbon dioxide and pH in ponds over 24 hours.

	Change		
Time	Dissolved Oxygen	Carbon Dioxide	pH
Daylight	Increases	Decreases	Increases
Nightime	Decreases	Increases	Decreases

Tucker (1984).

oxygen concentrations are above 5 mg/L. In a reservoir or natural pond, CO_2 rarely exceeds 5 to 10 mg/L.

High CO_2 concentrations are almost always accompanied by low dissolved oxygen concentrations (high respiration); the aeration used to increase low dissolved oxygen will, to some extent, help reduce excess CO_2 by improving its diffusion back into the atmosphere. Chronically high CO_2 levels can be treated chemically with hydrated lime, $Ca(OH)_2$. Approximately 1 mg/L of hydrated lime will remove 1 mg/L of CO_2. This treatment should not be used in waters with poor buffering capacity (low alkalinity) because pH could rise to levels lethal to fish. Also, fish could be endangered if hydrated lime is added to waters with high ammonia concentrations. High pH increases the toxicity of ammonia.

Alkalinity

The quantity of base present in water defines what is known as total alkalinity. Common bases found in fish ponds include carbonates, bicarbonates, hydroxides, phosphates and berates. Carbonates and bicarbonates are the most common and most important components of alkalinity. Alkalinity is measured by the amount of acid (hydrogen ion) water can absorb (buffer) before achieving a designated pH. Total alkalinity is expressed as milligrams per liter or parts per million calcium carbonate (mg/L or ppm $CaCO_3$). A total alkalinity of 20 mg/L or more is necessary for good pond productivity. A desirable range of total alkalinity for fish culture is between 75 and 200 mg/L $CaCO_3$.

Carbonate-bicarbonate alkalinity (and hardness) in surface and well waters is produced primarily through the interactions of CO_2, water and limestone. Rainwater is naturally acidic because of exposure to atmospheric carbon dioxide. As rain falls to the earth, each droplet becomes saturated with CO_2; and pH is lowered. Well water is pumped from large, natural underground reservoirs (aquifers) or small, localized pockets of underground water (groundwater), Typically, underground water has high CO_2 concentrations, and low pH and oxygen concentrations. Carbon dioxide is high in underground water because of bacterial processes in the soils and various underground, particulate mineral formations through which water moves. As ground- or rainwaters flow over and percolate through soil and underground rock formations containing calcitic limestone ($CaCO_3$) or dolomitic limestone [$CaMg(CO_3)_2$], the acidity produced by CO_2 will dissolve limestone and form calcium and magnesium bicarbonate salts:

$$CaCO_3 + H_2O + CO_2 = Ca^{+2} + 2HCO_3^-$$

or

$$CaMg(CO_3)_2 + 2H_2O + 2CO_2 = Ca^{+2} + Mg^{+2} + 4HCO_3^-$$

The resultant water has increased alkalinity, pH and hardness.

Alkalinity, pH and carbon dioxide concentrations

In water with moderate to high alkalinity (good buffering capacity) and similar hardness levels, pH is neutral or slightly basic (7.0 to 8.3) and does not fluctuate widely. Higher amounts of CO_2 (i.e., carbonic acid) or other acids are required to lower pH because there is more base available to neutralize or buffer the acid. The relation-

Table 2. Factors for calculating carbon dioxide concentrations in water with known pH, temperature and alkalinity measurements.[a]

	Temperatures (°C)						
pH	5	10	15	20	25	30	35
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	0.495	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

Tucker (1984).

[a] Factors should be multiplied by total alkalinity (mg/L) to get carbon dioxide (mg/L). For practical purposes, CO_2 concentrations are negligible above pH = 8.4.

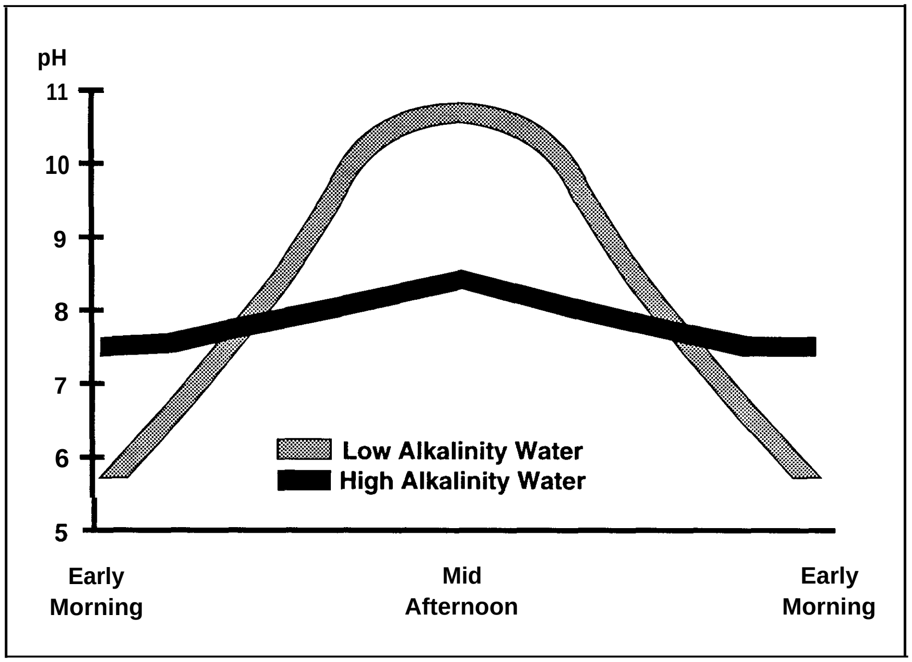

Figure 2. Changes in pH during a 24-hour period in waters of high and low total alkalinities.

ship among alkalinity, pH and CO_2 can be determined from Table 2. The number (factor) found in the table which corresponds to the measured pH and water temperature is multiplied by the measured alkalinity value (mg/L as $CaCO_3$). The product of these numbers estimates CO_2 concentration (mg/L).

For example, Mr. Jacobs measures a pH of 7.2, a temperature of 77°F (25°C) and total alkalinity of 103 mg/L in his catfish pond. He determines the corresponding factor, 0.124, from Table 2 and multiplies this number by the measured alkalinity, 103 mg/L. The resulting product gives him an estimate of the CO_2 concentration in his pond:

0.1 24x 103 mg/L alkalinity =
12.8 mg/L CO_2

A prompt pH measurement within 30 minutes of water sampling is required to minimize error when using this method. Due to several sources of error that can occur with this method, direct measurement of CO_2 using a chemical test procedure is preferred,

Alkalinity, pH and photosynthesis

The bases associated with alkalinity react with and neutralize acids. Carbonates and bicarbonates can react with both acids and bases and buffer (minimize) pH changes. The pH of well buffered water normally fluctuates between 6.5 and 9. In waters with low alkalinity, pH can reach dangerously low (CO_2 and carbonic acid from high respiration) or dangerously high (rapid photosynthesis) levels (Figure 2).

Phytoplankton are microscopic or near microscopic, aquatic plants which are responsible for most of the oxygen (photosynthesis) and primary productivity in ponds. By stabilizing pH at or above 6.5, alkalinity improves phytoplankton productivity (pond fertility) by increasing nutrient availability (soluble phosphate concentrations). Alkalinities at or above 20 mg/L trap CO_2 and increase the concentrations available for photosynthesis.

Because phytoplankton use CO_2 in photosynthesis, the pH of pond water increases as carbonic acid (i.e., CO_2) is removed. Also, phytoplankton and other plants can combine bicarbonates (HCO_3^-) to form CO_2 for photosynthesis, and carbonate (CO_3^{-2}) is released:

$$2HCO_3^- + \text{phytoplankton} = CO_2\text{(photosynthesis)} + CO_3^{-2} + H_2O)$$

$$CO_3^{-2} + H_2O = HCO_3^- + OH-$$
(strong base)

High pH could also be viewed as a decrease in hydrogen ions (H+):

$$CO_3^{-2} + H^+ = HCO_3^- \text{ or}$$
$$HCO_3^- + H^+ = H_2O + CO_2$$

The release of carbonate converted from bicarbonate by plant life can cause pH to climb dramatically (above 9) during periods of rapid photosynthesis by dense phytoplankton (algal) blooms. This rise in pH can occur in low alkalinity water (20 to 50 mg/L) or in water with moderate to high bicarbonate alkalinity (75 to 200 mg/L) that has less than 25 mg/L hardness. High bicarbonate alkalinity in soft water is produced by sodium and potassium carbonates which are more soluble than the calcium and magnesium carbonates that cause hardness. If calcium, magnesium and photosynthetically produced carbonate are present when pH is greater than 8.3, limestone is formed. Ponds with alkalinities below 20 mg/L do not usually support good phytoplankton blooms and do not commonly experience dramatic pH increases because of intense photosynthesis.

Hardness

Water hardness is important to fish culture and is a commonly reported aspect of water quality. It is a measure of the quantity of divalent ions (for this discussion, salts with two positive charges) such as calcium, magnesium and/or iron in water. Hardness can be a mixture of divalent salts; however, calcium and magnesium are the most common sources of water hardness.

Hardness is traditionally measured by chemical titration. The hardness of a water sample is reported in milligrams per liter as calcium carbonate (mg/L $CaCO_3$). Calcium carbonate hardness is a general term that indicates the total quantity of divalent salts present and does not specifically identify whether calcium, magnesium and/or some other divalent salt is causing water hardness.

Hardness is commonly confused with alkalinity (the total concentration of base). The confusion relates to the term used to report both measures, mg/L $CaCO_3$. If limestone is responsible for both hardness and alkalinity, the concentrations will be similar if not identical. However, where sodium bicarbonate ($NaHCO_3$) is responsible for alkalinity it is possible to have low hardness and high alkalinity. Acidic, ground or well water can have low or high hardness and has little or no alkalinity.

Calcium and magnesium are essential in the biological processes of fish (bone and scale formation, blood clotting and other metabolic reactions). Fish can absorb calcium and magnesium directly from the water or from food. However, calcium is the most important environmental, divalent salt in fish culture water. The presence of free (ionic), calcium in culture water helps reduce the loss of other salts (e.g., sodium and potassium) from fish body fluids (i.e., blood). Sodium and potassium are the most important salts in fish blood and are critical for normal heart, nerve and muscle function. Research has shown that environmental calcium is also required to re-absorb these lost salts. In low calcium water, fish can lose (leak) substantial quantities of sodium and potassium into the water. Body energy is used to re-absorb the lost salts. For some species (e.g., red drum and striped bass), relatively high concentrations of calcium hardness are required for survival.

A recommended range for free calcium in culture waters is 25 to 100 mg/L (63 to 250 mg/L $CaCO_3$ hardness). Channel catfish can tolerate low calcium concentrations as long as their feed contains a minimum level of mineral calcium but may grow slowly under these conditions. Similarly, rainbow trout can tolerate waters with free calcium concentrations as low as 10 mg/L if pH is above 6.5. If freshwater culture of striped bass, red drum or crawfish is being considered, free calcium concentrations in the 40 to 100 mg/L range (100 to 250 mg/L as $CaCO_3$ hardness) are desirable; a value of 100 mg/L (250 mg/ L calcium hardness) matches the calcium concentration of fish blood. Tests specific for calcium hardness should be performed on samples of the water source being considered for these animals.

A low $CaCO_3$ hardness value is a reliable indication that the calcium concentration is low. However, high hardness does not necessarily reflect a high calcium concentration. But, since limestone is common in the soil and bedrock of the southern United States, it would be reasonably safe to assume that high hardness measurements reflect high calcium levels.

A $CaCO_3$ hardness value of 100 mg/L represents a free calcium concentration of 40 mg/L (divide $CaCO_3$ value by 2.5) if hardness is caused by the presence of calcium only. Similarly, a $CaCO_3$ value of 100 mg/L represents a free magnesium value of 24 mg/L (divide $CaCO_3$ value by 4.12) if hardness is caused by magnesium only. These factors (2.5 and 4.12) are related to the molecular weight of $CaCO_3$ and the difference in weights between calcium and magnesium atoms. Where hardness is caused by limestone, the $CaCO_3$ value usually reflects a mixture of free calcium and magnesium with calcium being the predominant divalent salt.

Agricultural limestone can be used to increase calcium concentrations (and carbonate-bicarbonate alkalinity) in areas with acid waters or soils. However, at a pH of 8.3 or greater, agricultural limestone will not dissolve. Agricultural gypsum (calcium sulfate) or food grade calcium chloride could be used to raise calcium levels in soft, alkaline waters. Expense might be prohibitive if large volumes of water need treatment. Identifying a suitable water source may be more practical.

Effects of pH, alkalinity and hardness on ammonia and metal toxicities

Ammonia becomes more toxic as pH increases. Higher concentrations of the toxic form of ammonia (NH_3) are formed in basic waters; while the less toxic form, ammonium (NH_4^+), is more prevalent in acidic waters. Since alkalinity increases pH, ammonia will be more toxic in waters with high total alkalinity. Hardness is not typically associated with ammonia toxicity.

Metals such as copper and zinc are commonly used around aquatic environments (tanks, plumbing and copper sulfate). These metals become more soluble in acidic environments. The soluble or free ionic forms of these metals are toxic to fish. High total alkalinity increases pH and available bases which produce less toxic or insoluble forms of copper and zinc. High concentrations of calcium and magnesium (hardness) block the effects of copper and zinc at their sites of toxic action. Therefore, copper and zinc are more toxic to fish in soft, acidic waters with low total alkalinity.

Ideally, an aquaculture pond should have a pH between 6.5 and 9 as well as moderate to high total alkalinity (75 to 200, but not less than 20 mg/L) and a calcium hardness of 100 to 250 mg/L $CaCO_3$. Many of the principles of chemistry are abstract (e.g., carbonate-bicarbonate buffering) and difficult to grasp. However, a fundamental understanding of the concepts and chemistry underlying the interactions of pH, CO_2, alkalinity and hardness is necessary for effective and profitable pond management. There is no way to avoid it; water quality is water chemistry.

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The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 89-38500-4516 from the United States Department of Agriculture.

SRAC Publication No. 463

**Southern
Regional
Aquaculture
Center**

June 1997
Revised

Ammonia in Fish Ponds

Robert M. Durborow[1], David M. Crosby[2] and Martin W. Brunson[3]

Ammonia is the major end product in the breakdown of proteins in fish. Fish digest the protein in their feed and excrete ammonia through their gills and in their feces. The amount of ammonia excreted by fish varies with the amount of feed put into the pond or culture system, increasing as feeding rates increase. Ammonia also enters the pond from bacterial decomposition of organic matter such as uneaten feed or dead algae and aquatic plants.

Forms and toxicity

Total ammonia nitrogen (TAN) is composed of toxic (un-ionized) ammonia (NH_3) and nontoxic (ionized) ammonia (NH^+_4). Only a fraction of the TAN exists as toxic (un-ionized) ammonia, and a balance exists between it and the nontoxic ionized ammonia:

$$H^+ + (NH_3 \rightleftharpoons (NH^+_4)$$

The proportion of TAN in the toxic form increases as the temperature and pH of the water increase. For every pH increase of one unit, the amount of toxic un-ionized ammonia increases about 10 times. The amount of toxic un-ionized ammonia in your pond can be found by measuring the TAN with a water quality test kit and then looking up the fraction of TAN that is in the toxic form on Table 1, which is based on water temperature and pH. Multiply this fraction by the TAN to find the concentration (mg/L or ppm) of toxic un-ionized ammonia present in the water. For example, if water pH is 8.6, water temperature is 30°C, and TAN is 3 mg/L (ppm), multiply 0.2422 (from Table 1) by 3 mg/L (ppm) to obtain 0.73 mg/L (ppm) toxic un-ionized ammonia.

Uptake (assimilation) of ammonia by plankton algae is important in reducing the amount of ammonia coming in contact with fish. Ammonia increases in the fall and winter because of reduced algae populations in the pond and algae populations which are not as capable of taking ammonia from the water. Additionally, lower water temperatures slow down aerobic bacterial activity, thus slowing the nitrification process whereby ammonia is converted to harmless nitrate (Figure 1). Algae die-offs can also lead to very high ammonia concentrations, but, fortunately, the low pH associated with the disappearance of the algae reduces the proportion of toxic un-ionized ammonia present.

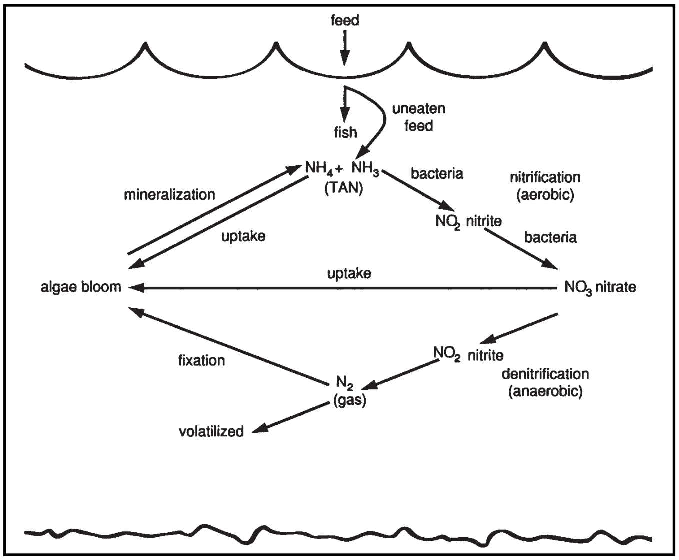

Figure 1. Nitrogen cycle in a fish pond.

Dangerous short-term levels of toxic un-ionized ammonia which are capable of killing fish over a few days start at about 0.6 mg/L (ppm). Chronic exposure to toxic un-ionized ammonia levels as low as 0.06 mg/L (ppm) can cause gill and kidney damage, reduction in growth, possible brain malfunc-

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[1] Cooperative Extension Program, Kentucky State University
[2] Virginia State University
[3] Mississippi Cooperative Extension Service

tioning, and reduction in the oxygen-carrying capacity of the fish.

Treatments

Treatment for high TAN concentrations is difficult in large pond culture systems. Pumping fresh water into the pond is not a practical or economical means of reducing the ammonia level for the whole pond. It does, however, provide a small area near the inflowing water where fish can go to find some relief. Maintaining high dissolved oxygen levels by aeration will slightly reduce the toxic effect of un-ionized ammonia. In addition, TAN levels may be reduced through increased aerobic bacterial activity due to higher oxygen levels. Temporary reduction of feeding rates is recommended until TAN levels decrease to an acceptable level.

Prevention of high TAN is a better approach to the problem. The use of lower feeding rates and good feeding practices play a big role in keeping TAN levels low. Problems with high TAN concentrations can be expected when feeding rates exceed 100 pounds per acre per day, or when excessive feed waste is occurring. Fish should not be overfed, and the feeder should be sure that fish are consuming feed offered. This is both of practical and economic importance, since feed costs are a major portion of production costs.

With pond and tank stocking densities continually increasing, it is not often considered economically practical to reduce feeding rates. However, the organic loading in these systems is a major factor that must be dealt with. Intensive recirculating systems may be better suited to handle these excessive amounts of nitrogen, but most pond systems probably have a finite limit to the amount of nitrogen and organic loading that can be managed. Unless more efficient management methods are developed, nitrogen and organic loading may become a limiting factor in stocking and production rates in culture ponds.

Table 1. Fraction of toxic (un-ionized) ammonia in aqueous solutions at different pH values and temperatures. Calculated from data in Emerson, et al. (1975). (To determine the amount of un-ionized ammonia present, get the fraction of ammonia that is in the un-ionized form for a specific pH and temperature from the table. Multiply this fraction by the total ammonia nitrogen present in a sample to get the concentration in ppm (mg/L) of toxic (un-ionized) ammonia.)

	Temperatures (°C)												
pH	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**
7.0	.0013	.0016	.0018	.0022	.0025	.0029	.0034	.0039	.0046	.0052	.0060	.0069	.0080
7.2	.0021	.0025	.0029	.0034	.0040	.0046	.0054	.0062	.0072	.0083	.0096	.0110	.0126
7.4	.0034	.0040	.0046	.0054	.0063	.0073	.0085	.0098	.0114	.0131	.0150	.0173	.0198
7.6	.0053	.0063	.0073	.0086	.0100	.0116	.0134	.0155	.0179	.0206	.0236	.0271	.0310
7.8	.0084	.0099	.0116	.0135	.0157	.0182	.0211	.0244	.0281	.0322	.0370	.0423	.0482
8.0	.0133	.0156	.0182	.0212	.0247	.0286	.0330	.0381	.0438	.0502	.0574	.0654	.0743
8.2	.0210	.0245	.0286	.0332	.0385	.0445	.0514	.0590	.0676	.0772	.0880	.0998	.1129
8.4	.0328	.0383	.0445	.0517	.0597	.0688	.0790	.0904	.1031	.1171	.1326	.1495	.1678
8.6	.0510	.0593	.0688	.0795	.0914	.1048	.1197	.1361	.1541	.1737	.1950	.2178	.2422
8.8	.0785	.0909	.1048	.1204	.1376	.1566	.1773	.1998	.2241	.2500	.2774	.3062	.3362
9.0	.1190	.1368	.1565	.1782	.2018	.2273	.2546	.2836	.3140	.3456	.3783	.4116	.4453
9.2	.1763	.2008	.2273	.2558	.2861	.3180	.3512	.3855	.4204	.4557	.4909	.5258	.5599
9.4	.2533	.2847	.3180	.3526	.3884	.4249	.4618	.4985	.5348	.5702	.6045	.6373	.6685
9.6	.3496	.3868	.4249	.4633	.5016	.5394	.5762	.6117	.6456	.6777	.7078	.7358	.7617
9.8	.4600	.5000	.5394	.5778	.6147	.6499	.6831	.7140	.7428	.7692	.7933	.8153	.8351
10.0	.5745	.6131	.6498	.6844	.7166	.7463	.7735	.7983	.8207	.8408	.8588	.8749	.8892
10.2	.6815	.7152	.7463	.7746	.8003	.8234	.8441	.8625	.8788	.8933	.9060	.9173	.9271

Source: Emerson, K., R.C. Russo, R.E. Lund, and R.V. Thurston. 1975. *Aqueous ammonia equilibrium calculations: effect of pH and temperature.* Journal of the Fisheries Research Board of Canada. 32:2379-2383.

The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 94-38500-0045 from the United States Department of Agriculture, Cooperative States Research, Education, and Extension Service.

SRAC Publication No. 462

**Southern
Regional
Aquaculture
Center**

June 1997
Revised

Nitrite in Fish Ponds

Robert M. Durborow[1], David M. Crosby[2] and Martin W. Brunson[3]

Nitrite enters a fish culture system after feed is digested by fish and the excess nitrogen is converted into ammonia, which is then excreted as waste into the water. Total ammonia nitrogen (TAN; NH_3 and $NH4^{+}$) is then converted to nitrite (NO_2) which, under normal conditions, is quickly converted to non-toxic nitrate (NO_3) by naturally occurring bacteria (Figure 1). Uneaten (wasted) feed and other organic material also break down into ammonia, nitrite, and nitrate in a similar manner.

Brown blood disease occurs in fish when water contains high nitrite concentrations. Nitrite enters the bloodstream through the gills and turns the blood to a chocolate-brown color. Hemoglobin, which transports oxygen in the blood, combines with nitrite to form methemoglobin, which is incapable of oxygen transport. Brown blood cannot carry sufficient amounts of oxygen, and affected fish can suffocate despite adequate oxygen concentration in the water. This accounts for the gasping behavior often observed in fish with brown blood disease, even when oxygen levels are relatively high.

Nitrite problems are typically more likely in closed, intensive culture systems due to insufficient, inefficient, or malfunctioning filtration systems. High nitrite concentrations in ponds occur more frequently in the fall and spring when temperatures are fluctuating, resulting in the breakdown of the nitrogen cycle due to decreased plankton and / or bacterial activity. A reduction in plankton activity in ponds (because of lower temperatures, nutrient depletion, cloudy weather, herbicide treatments, etc.) can result in less ammonia assimilated by the algae, thus increasing the load on the nitrifying bacteria (Figure 1). If nitrite levels exceed that which resident bacteria can rapidly convert to nitrate, a buildup of nitrite occurs, and brown blood disease is a risk. Although nitrite is sel-

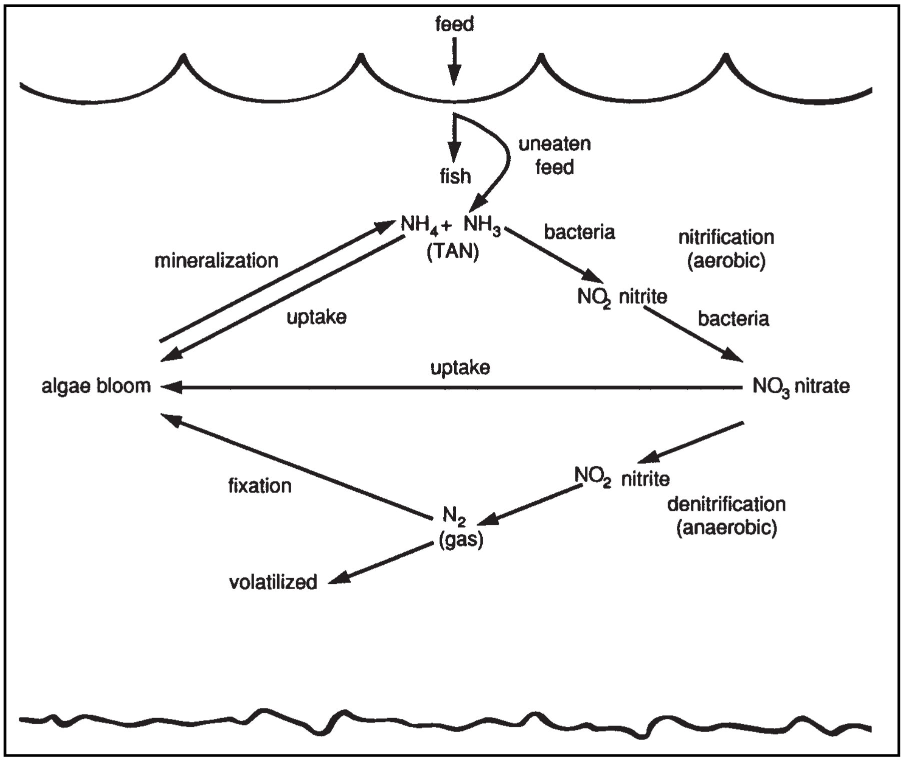

Figure 1. Nitrogen cycle in a fish pond.

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[1] Cooperative Extension Program, Kentucky State University

[2] Virginia State University

[3] Mississippi Cooperative Extension Service

dom a problem in systems with high water exchange rates or good filtration, systems should be monitored year-round, and managed when necessary, to prevent severe economic loss from brown blood in any fish culture facility.

Susceptibility of fish species to nitrite toxicity

Largemouth and smallmouth bass, as well as bluegill and green sunfish, are resistant to high nitrite concentrations. The Centrarchids apparently are able to effectively prevent nitrite from entering the gills, but most other warmwater fishes grown in the Southeast apparently concentrate nitrite in the blood. Catfish and tilapia, for example, are fairly sensitive to nitrite, and trout and other coolwater fish are sensitive to extremely small amounts of nitrite. Goldfish and fathead minnows fall in between catfish and bass in their susceptibility to brown blood disease resulting from high nitrite levels. Striped bass and its hybrids appear sensitive to nitrite, but little is known about the relative sensitivity compared to other species.

Treatment and prevention

Since this is a nitrogen-related problem, the most obvious preventive measure is to reduce or minimize the amount of nitrogen incorporated into the system by reducing feeding rates. However, in modern intensive pond or closed system fish culture with high densities and rapid growout, longterm feed reduction is not considered by most farmers as a viable option. Luckily, although we often cannot prevent the occurrence of high nitrite, its effects can be minimized or neutralized safely and economically.

Sodium chloride (common salt, NaCl) is used to “treat” brown blood disease. Calcium chloride can also be used but is typically more expensive. The chloride portion of salt competes with nitrite for absorption through the gills. Maintaining at least a 10 to 1 ratio of chloride to nitrite in a pond effectively prevents nitrite from entering catfish. Where catfish (or other fish) have bacterial and / or parasite diseases, their sensitivity to nitrite may be greater, and a higher chloride-to-nitrite ratio may be needed to afford added protection from nitrite invasion into the bloodstream. As a general rule, catfish producers strive to maintain at least 100 ppm chloride in pond waters as “insurance” against high spikes of nitrite concentration. Culturists of other species may want to assume that nitrite is a potential problem and use salt as an insurance buffer as well.

How to calculate the amount of salt needed

Before treatment rates can be calculated, chloride and nitrite concentrations in the water, as well as pond or tank volume, must be determined. Commercially available water quality test kits can be used. Contact your Extension fisheries or aquaculture specialist for assistance in locating sources for test kits and conducting and interpreting these tests.

The amount of salt needed for the pond can be calculated using the following formulas:

Formula 1

(10 x pond nitrite concentration) - (pond chloride concentration) = parts per million (ppm) of chloride to add to the pond

The number “10” used in this formula is the minimum desired chloride:nitrite ratio number. It is used here to get a 10 to 1 chloride to nitrite ratio. If a higher ratio is desired, substitute the higher number for the 10.

If the answer is zero or a negative number, chloride concentration is sufficient to prevent brown blood disease.

Use the answer from Formula 1 above in the following formula:

Formula 2

Surface acres x average depth in feet x ppm of chloride to add to the pond x 4.5 = pounds of salt (NaCl) needed to add to the pond

You need 4.5 pounds of salt to increase the chloride concentration by 1 ppm in an acre-foot of water.

Example

The following readings are obtained from a 20-acre catfish pond with an average depth of 4 feet:

4 ppm nitrite
15 ppm chloride

Use Formula 1:

(10 x 4 ppm nitrite) - 15 ppm chloride in the pond = 40 - 15 = 25 ppm chloride to add to the pond

Now use Formula 2:

20 acres x 4 feet average depth x 25 ppm chloride to add to the pond x 4.5 = 9,000 pounds of salt needed to add to the pond

Application of salt

Distribute the salt evenly and quickly when fish are suffering from brown blood disease. Farmers have used feed trucks, airplanes, paddle wheels, and front-end loaders to distribute salt. It takes about 24 hours after salt is applied to a pond for the brown blood condition to be alleviated.

A good water quality monitoring program can help prevent brown blood disease. Pond water should be checked for nitrite two to three times a week during fall and spring, and at least weekly the remainder of the year. We recommend maintaining a chloride-to-nitrite ratio of at least 10:1 for catfish. Check ponds daily during a known high nitrite incident, even if adequate chlorides are in the ponds. Also check chloride after periods of heavy rain or active flushing from well water; both these events can dilute chloride concentrations and reduce the chloride:nitrite ratio.

Nitrite can increase very suddenly, so it is advisable to keep a 100 ppm chloride concentration at all times to act as a buffer when nitrite suddenly increases. This is a standard practice in the catfish industry, and incidents of brown blood disease in catfish ponds have become very rare. As an example, if your water has a chloride concentration of 20 ppm and you want to increase it to 100 ppm, simply add 80 ppm chloride to your pond. Use Formula 2 to calculate the pounds of salt needed.

Another way to help manage brown blood disease is by checking total ammonia nitrogen (TAN) concentrations in ponds every week. Every 1 ppm TAN can convert to 3 ppm nitrite in a relatively short period. High TAN levels can alert the farmer to anticipate nitrite problems within a few days, and nitrite problems can thus be predicted and then prevented.

In many areas, water contains high natural concentrations of chloride, and addition of salt as “insurance” is not needed. Water should still be monitored frequently, however, since chloride levels can fluctuate widely and frequently.

Outlook

Brown blood disease can be prevented, or at least minimized, by close monitoring of nitrite, chloride, and TAN, and by maintaining the proper chloride-to-nitrite ratio. If brown blood disease does occur, the condition can be reversed by adding salt to the water. Catfish (and likely other fish) surviving brown blood disease or nitrite stress are more susceptible to bacterial infections, anemia (white-lip or no-blood), and other stress-related diseases. Secondary problems, such as Aeromonas and Columnaris bacterial infections, often occur 1 to 3 weeks after brown blood disease occurs.

Research is currently underway to determine whether even higher levels of chloride may be beneficial in reducing sub-lethal, chronic stress on fish from nitrite or other stressing factors. Results have thus far indicated significant advantages to maintaining chloride levels as high as practically possible.

The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 94-38500-0045 from the United States Department of Agriculture, Cooperative States Research, Education and Extension Service.