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## Pond Mixing

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The upper layers of pond water absorb light, so most aquaculture ponds will develop stratification during the summer. This condition is characterized by extreme differences in water quality—especially temperature and dissolved oxygen concentration—between surface and bottom waters. These differences in water quality can affect fish culture. Many fish species will move to areas of preferred water quality and may be “squeezed” into relatively narrow bands of the water column. Mechanically mixing pond water creates a more uniform environment and increases the pond volume that can be occupied by fish.

Most levee-type aquaculture ponds are shallow, so strong winds blowing over the pond surface mix the water somewhat. However, wind is unpredictable and unreliable for pond mixing. Winds are often light in the summer when the respiration rates of pond organisms are high, the demand for oxygen is greatest, and mixing would be most beneficial. Winds also are usually calmest at night, when the dissolved oxygen concentration is low and wind blowing across the pond surface would add oxygen to the water.

Mechanical mixing of pond water is more reliable than wind. Although aeration devices are widely used in commercial aquaculture ponds, pond mixing devices are not commonly used. Pond mixing is also known as water blending, water circulation, artificial circulation, or destratification. There are several mechanical techniques for reducing stratification.

### Stratification—the layering of pond water

Stratification is caused by the absorption of sunlight energy by pond water. The intensity of sunlight decreases exponentially with water depth (Fig. 1). Surface waters are brightly lit and deeper waters are dimly lit. Water absorbs about 30 percent of the energy in sunlight as heat. As

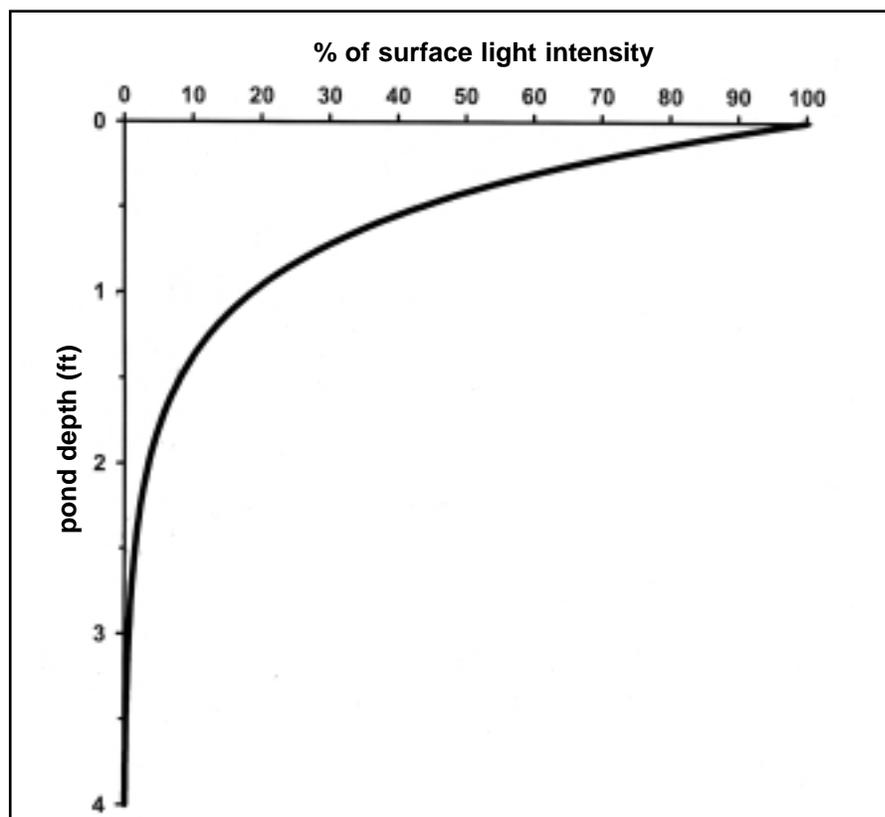


Fig. 1. In a pond with a dense algae bloom, light intensity decreases exponentially from the surface to the bottom. Much of the water column in such a pond is dimly lit or dark.

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surface water absorbs this energy it becomes warmer and less dense than the water that lies beneath.

The result is warmer, less dense layers of water that float over the top of cooler, more dense layers of water.

Stratification becomes much more pronounced as turbidity increases because turbidity restricts the penetration of sunlight into the water column. The primary cause of turbidity is suspended matter (organic solids such as algae or inorganic solids such as clay particles) in the water column.

The degree of stratification in a pond can be calculated by finding the difference between surface and bottom water temperatures and dividing by pond depth. This gives a rate of temperature change with depth, in units of degrees per foot. During the summer, it is not unusual for the surface waters of aquaculture ponds to be 10 to 20 degrees warmer than bottom waters.

The maximum depths of aquaculture ponds range from 3 to 5 feet for levee ponds to 10 to 15 feet for watershed ponds. During the summer, both types of ponds will stratify during the day and destratify at night (Fig. 2).

Maximum stratification usually occurs between 2:00 and 4:00 p.m. on calm days. Ponds deeper than 6 to 10 feet may not mix all the way to the bottom at night, which causes a persistent layer of poor quality water that is temporarily disrupted only during storms strong enough to “turn” the pond water. Without natural disturbance or mechanical mixing, deeper watershed ponds can have a cold, deep layer that remains throughout the summer, even though the surface layer stratifies and destratifies daily.

Although stratification usually refers to water layers with different temperatures, the term also can refer to layers with different chemical concentrations—specifically, dissolved oxygen concentra-

tion. Because there is more light near the surface, photosynthesis by algae is also greater near the surface. Photosynthesis produces oxygen. What little oxygen is produced at the pond bottom is often consumed by the decomposition of organic matter. Therefore, surface water contains much more dissolved oxygen than bottom water. On calm, sunny, summer mid-afternoons the dissolved oxygen concentration can range from more than 15 mg/L at the surface to less than 4 mg/L at the bottom. The temperature-related density stratification prevents the surface dissolved oxygen from mixing into the deeper waters.

Chemical stratification affects the accurate measurement of dissolved oxygen concentration (see SRAC publication 4601). Measurements near the surface might not reflect the quality of water available for species, such as freshwater prawns, that live on or near the pond bottom. Severe dissolved oxygen stratification can force such species into shallow water where they are susceptible to cannibalism, predation by wading birds, or the effects of warmer water.

## Potential benefits of mixing

Mixing is thought to benefit both the pond ecosystem and fish growth and survival. Although the benefits described below have not all been conclusively demonstrated by research, the results of lake remediation projects suggest that mixing can improve fisheries and perhaps fish production in aquaculture ponds.

### *Improves distribution of dissolved oxygen through the water column*

Effective mixing creates a homogeneous environment throughout the pond water column. In unmixed ponds with dense algae blooms, photosynthesis is confined to the surface layers because that is where light levels are most intense. In these ponds, photosynthesis at the surface will result in very high dissolved oxygen con-

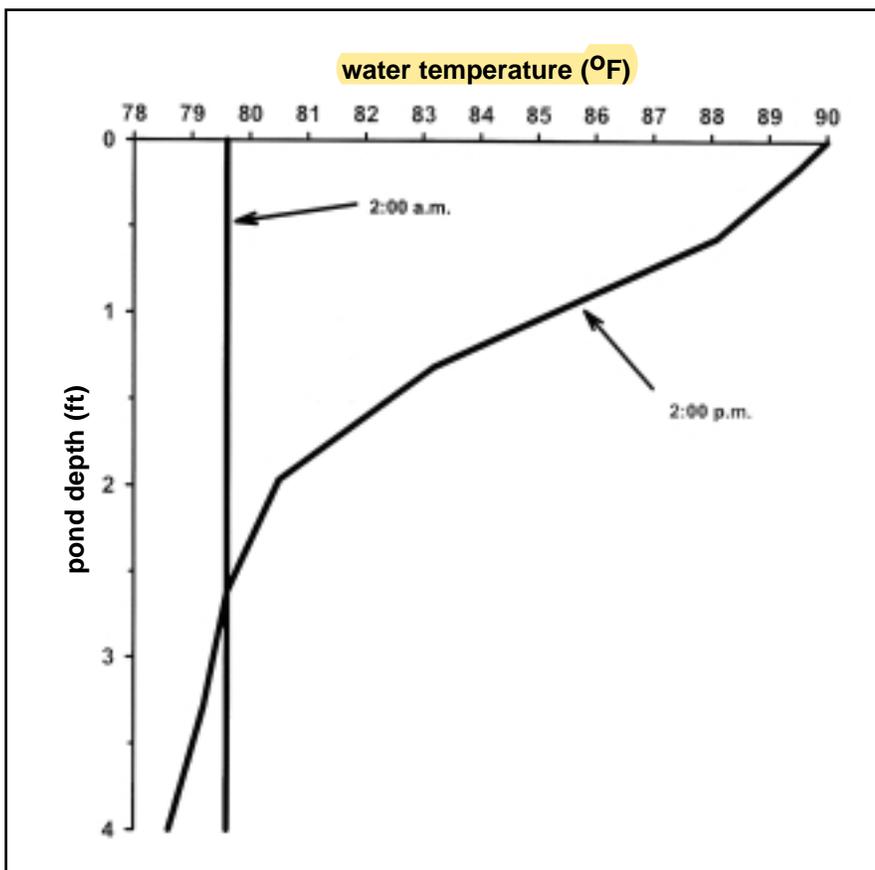


Figure 2. Ponds with dense algae blooms will stratify during the day and destratify at night. Differences between surface and bottom temperatures during the day can be more than 10 degrees F.

centration near the pond surface and very low dissolved oxygen concentration at the pond bottom. Surface dissolved oxygen concentration often exceeds saturation (the equilibrium concentration of oxygen that water can “hold” at a certain temperature, salinity and barometric pressure). In this case, dissolved oxygen diffuses from the water to the atmosphere and is lost from the pond. Pond mixing conserves the dissolved oxygen produced by photosynthesis and distributes supersaturated surface waters throughout the pond. This increases the total supply of oxygen available for fish at night. Mixing at night, when the dissolved oxygen concentration is below saturation, helps diffuse oxygen from the air into water.

#### ***Minimizes organic matter accumulation***

Redistributing surface waters can have a positive effect on processes that occur on the pond bottom. The population of algae is constantly turning over so that a certain fraction dies and settles out every day. Once it settles to the pond bottom, this organic matter decomposes rapidly, creating a large demand for oxygen. So, the oxygen concentration of the water near the pond bottom tends to be low. Redistributing the oxygen in surface water layers accelerates the decomposition of organic matter so that excessive amounts don't accumulate in pond sediment. Without oxygen near the pond bottom, decomposition results in the production of various chemical compounds (such as volatile fatty acids and various fermentation products), some of which are toxic to fish and may reduce fish growth in some ponds. Therefore, mixing may prevent the accumulation of toxic chemical compounds.

#### ***Reduces density of algae blooms***

Mixing may reduce the density of algae blooms by lowering the concentration of soluble phosphorus in pond water. Of all the nutrients added to freshwater ponds in feed or fertilizer, phosphorus is most

important for algae growth. Theoretically, reducing phosphorus concentration can reduce the density of algae blooms, thereby reducing the risk of oxygen depletions and the potential for fish kills. Mixing maintains a high dissolved oxygen concentration near the pond bottom, which causes the development of a thin, oxygenated layer or “crust” at the sediment-water interface. This barrier prevents phosphorus from diffusing into the water and keeps it “locked up” in pond sediment. Although this process has been demonstrated in lakes and reservoirs, it has not been conclusively documented in fish ponds.

#### ***Shifts composition of algae blooms***

Mixing may affect the species composition of algae blooms. This is important with respect to the potential control of off-flavor caused by blue-green algae.

When algae blooms become very dense, further expansion of the blooms is limited by the availability of light for photosynthesis. Algae blooms in most commercial aquaculture ponds are sufficiently dense to be limited by light. Algae blooms that are limited by light tend to favor the growth of blue-green algae because they compete better for light than other kinds of algae. Blue-green algae are also favored by a stable water column, which occurs when a pond stratifies. Theoretically, then, mixing will limit the growth of blue-green algae.

Although research on the species composition of algae blooms in mixed versus unmixed ponds is scant, there is some evidence to suggest that mixing can affect the species composition of algae blooms. If mixing can reduce the prevalence of blue-green algae in blooms, then mixing may be an effective way of managing off-flavors caused by blue-green algae.

#### ***Energy considerations***

In the commercial catfish industry, producers generally operate paddlewheel aerators at 1 to 2 hp/acre for approximately 1,000

hours during each production season. This represents the investment in electric power producers are willing to make to obtain a production level of 4,000 to 6,000 pounds per acre. If this level of electric power investment is a given, then should power be allocated exclusively to paddlewheel aeration? Perhaps installing both mixers and aerators in the same pond can reduce the overall power requirement. The limited research on the subject showed that operating an axial-flow circulator for 6 to 8 hours during the middle of the day reduced the need for paddlewheel aeration by 58 percent. However, the combined power requirement of the mixer and the paddlewheel aerator was very similar to that of the paddlewheel aerator alone. Fish production in ponds with a mixer and an aerator was similar to that in ponds with only an aerator, so there was no economic justification for mixing in that study. However, the mixing efficiency of the device used was low.

In fact, the mixing efficiency of most devices used to circulate pond water is very low, on the order of 0.1 percent. This can be explained by the fact that the energy is usually applied at a single point and turbulence emanates only from that point. The amount of energy required to mix a stratified water column to a uniform temperature (or, more properly, density) is actually quite low. The problem is that this density gradient extends throughout the pond. This presents a formidable engineering challenge, one that can't be solved simply by using mixing equipment that creates turbulence at more than one point. The effectiveness of mixing equipment can be increased by installing vertical baffles along the long axis of the pond to direct water flow and help create a uniform flow throughout the water column.

#### ***Mixing devices***

Many devices have been used to mix ponds. Most mechanical aerators provide some mixing, although their primary purpose is to add dissolved oxygen to the

water. The types of mixing devices that are effective in commercial catfish ponds are constrained by the relatively large pond size (20 acres), shallow depth (3 to 5 feet), and intense stratification. The most efficient mixing devices move very large volumes of water against a very low head (1/2 to 2 inches) compared to the amount of power applied.

In some lakes, reservoirs and deeper watershed ponds, destratification equipment is operated to expand the pond volume that can be occupied by fish and to improve water quality. Destratifiers typically operate by lifting water from deeper parts of the lake to the surface, or by pushing water from the surface toward the bottom. Some destratifiers have large fan blades that move water vertically; others release air near the pond bottom to lift water. This equipment works well in lakes and reservoirs that are much deeper than aquaculture ponds, but destratifiers rarely destratify large lakes completely. Rather, they create a zone of well-mixed water near the destratifier. In shallow aquaculture ponds, vertical water movement is not as effective as horizontal water movement. Therefore, this section will emphasize mixing devices that move water horizontally.

### **Paddlewheel aerator**

Adding dissolved oxygen to pond water is the primary purpose of paddlewheel aerators. They splash water into the air and generate turbulence adjacent to the aerator. The shaft usually rotates at a fairly high speed (75 to 80 rpm). In commercial catfish ponds, a paddlewheel aerator creates a zone of well oxygenated water that is a refuge for fish when dissolved oxygen concentration in most of the pond is very low.

If paddlewheel aerators are operated continuously, particularly if several aerators are placed in strategic locations, the pond can become well mixed. However, paddlewheel aerators are not effi-

cient mixing devices, which is true of aerators designed primarily to provide oxygen to the pond.

Operating paddlewheel aerators during the day mixes water well, but causes a net loss of oxygen from the pond. This occurs because mechanical disturbance drives out dissolved oxygen if water is supersaturated with oxygen. More gentle mixing may permit more dissolved oxygen to accumulate and to be mixed into deeper water.

### **Propeller-aspirator pump**

Propeller-aspirator pumps consist of an electric motor connected to a hollow shaft with a propeller at the end. The motor rests on a float above the water surface and the hollow shaft extends into the water at an angle. There are holes cut in the part of the shaft that is above the water surface. As the shaft rotates and water is pushed out ahead of the propeller, air is drawn into the holes and ejected through the end of the shaft.

These devices circulate water better than other mechanical aerators. Unlike paddlewheel aerators, which create a surface current and a return current along the bottom, propeller-aspirator pumps create a current along the bottom and a return flow along the surface.

### **Axial-flow water circulator**

Various designs of axial-flow water circulators have been evaluated. They move water with wide (6-inch), large-diameter (24- to 30-inch) fan blades attached to a shaft that is connected to a gear motor mounted above the water surface. The unit depicted in Figure 3 has the fan blades mounted on a shaft within a casing 4 feet long and 3 feet in diameter. The circulator has three or four fan blade units, each with six blades. The shaft rotates at 120 to 140 rpm and is powered by a 2.5- or 3-hp gear motor. This combination produces a water discharge of about 12,000 gallons/minute.

Axial-flow circulators should be mounted to a solid surface, such as a wooden platform, on the pond bottom. The circulator should be placed in a corner of the pond and should direct water flow along a long side of a rectangular pond.

### **Low-speed paddlewheel**

Low-speed paddlewheels (Fig. 4) are a central component of the partitioned aquaculture system (PAS) developed and evaluated by engineers at Clemson University. The PAS consists of a high-density fish culture raceway coupled with

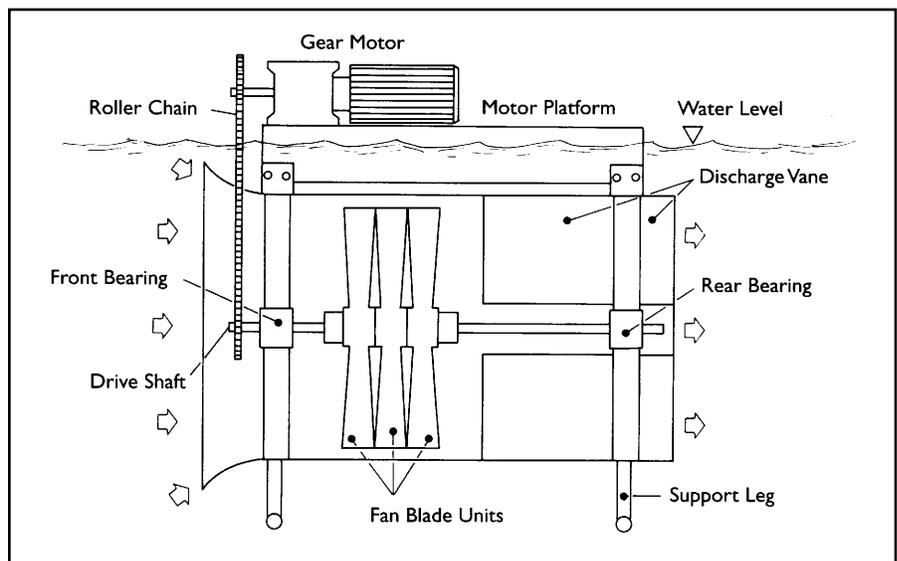


Figure 3. Side view of an axial-flow water circulator for pond mixing. Reprinted from C. S. Tucker and J. A. Steeby. 1995. Daytime mechanical water circulation of channel catfish ponds, pp. 15-27, Aquacultural Engineering, Vol. 14, with permission from Elsevier Science.



Figure 4. Hydraulic-powered, low-speed paddlewheel used to mix the partitioned aquaculture system. Paddlewheels rotate at 1 to 3 rpm. Photo: John Collier.

a shallow (1.5-foot), baffled, open pond area where luxuriant algae growth occurs. A high rate of algae growth is necessary to treat the large quantities of waste products produced in the fish culture raceway. The low-speed paddlewheel moves a large water volume at a constant and low velocity (3 to 4 inches/second) throughout the pond.

Paddles are constructed of sheet steel welded to an angle-iron frame. Each paddle is typically 16 feet long by 3 feet wide and is operated with 1.5 feet of the paddle submerged. A completed paddlewheel assembly has six paddles welded to the shaft.

The paddlewheels rotate at 1 to 3 revolutions per minute, driven by an oil hydraulic system pressurized by a 3-hp electric motor, although the actual power requirement is much less (about 1 to 1.25 hp). A 3-hp electric motor connected to a hydraulic system powering four 16-foot paddles can move more than 22,000 gallons/minute.

In many respects, a low-speed paddlewheel is an ideal mixing device because it can move a large volume of water against a very low head with very little energy. In conjunction with baffles placed along the pond length, it can create a flow field that is uniform throughout the water column.

### Tractor-powered "side-winder"

Tractor-powered paddlewheel aerators have been widely used for emergency aeration of commercial catfish ponds. The paddlewheel hub of the unit is attached to a drive shaft that connects to the power take-off (PTO) of a tractor. Most tractor-powered paddlewheel aerators move water away from the pond bank. However, some tractor-powered paddlewheel aerators, called "side-winders" or "bank-washers," have long paddles mounted on a hub and create a current parallel to the pond bank. To maximize oxygen transfer, the devices are operated with paddlewheels submerged at an intermediate depth and at an intermediate engine speed. To obtain good pond mixing, paddles should be fully submerged and the tractor engine set at idle speed. Two tractors on opposite sides of the long levees of a pond can mix a pond completely in 2 to 3 hours.

### Operational considerations

The type of mixing device selected determines the number of devices needed, their placement, and the timing of operation. It is important to emphasize that to be beneficial, most of the water volume in a pond should be circulated. Mixing only a corner of a

pond or a small area near a paddlewheel aerator is of limited benefit.

Most commercial catfish ponds are large (10 to 20 acres) and rectangular. These ponds are difficult to mix. In general, mixing devices should be placed so that water is directed along the long axis of the pond. The effectiveness of many mixing devices can be improved by constructing one or more baffle levees within the pond, although baffle levees will increase suitable habitat for wading birds and other nuisance wildlife and interfere with normal harvest operations. Rather than retrofitting existing ponds with mixing equipment, the best method is to configure ponds during construction so that mixing is incorporated into pond design. The PAS is one example of this approach.

The best time for operating equipment varies somewhat with the goal of mixing. If the goal is increasing the dissolved oxygen concentration at the pond bottom or conserving dissolved oxygen produced by photosynthesis during the day for use at night, then it is most effective to operate equipment for several hours during mid-day before maximum stratification occurs. Intermittently operated mixing devices should be on for 3 to 8 hours during the day and turned off at night.

In some production settings, such as the PAS, continuous mixing may be warranted. In this case, mixing at night will accelerate the diffusion of oxygen from the air into the water. Dissolved oxygen will be lost from ponds where some types of mixing equipment (such as paddlewheel aerators) are operated during the day. However, there is often more oxygen produced in continuously mixed ponds than in static ponds.

Depending on the pond type, the species cultured, and the climatic conditions in a given location, timely mixing of ponds may be beneficial. Yet both technical and economic questions remain unresolved. At this point, it is not known whether the costs outweigh the actual benefits.

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