United States
Department of
Agriculture

Natural
Resources
Conservation
Service

AGRICULTURAL ENGINEERING

Technical Note No. AEN-3

July 2011

AERATION OF PONDS USED IN AQUACULTURE

Acknowledgments

This technical publication was authored by **Perry L. Oakes**, P.E., State Conservation Engineer, United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Auburn, AL; **Kale Gullett**, Fisheries Biologist, NRCS East National Technical Support Center (ENTSC) Greensboro, NC; and **Todd Bobowick**, Resource Conservationist, NRCS Hamden, CT.

The technical note was developed under the direction of **Noller Herbert**, P.E., Director, USDA NRCS Conservation Engineering Division, Washington, DC, and **Wayne M. Bogovich**, P.E., National Agricultural Engineer, USDA NRCS Conservation Engineering Division, Washington, DC.

Reviewers included **Claude E. Boyd**, Ph.D., Auburn University, Auburn, AL; **Gregory N. Whitis, Alabama Cooperative Extension System (ACES), Greensboro, AL; Craig S. Hollingsworth**, Ph.D., and **James B. Webb, PhD.,** University of Massachusetts, Amherst, MA; **Jeff Gunderson**, University of Minnesota, Twin Cities Campus, Minneapolis, MN; and **Joseph E. Morris**, Ph.D., Iowa State University, Ames, IA.

Aeration of Ponds used in Aquaculture

Issued July 2011

Contents

I. Introduction 1

II. Dissolved oxygen dynamics in ponds 1

Sources of dissolved oxygen 1

Oxygen balance and stratification 2

Ponds at higher latitude and altitude 3

Measuring dissolved oxygen 3

DO concentrations for production 4

Oxygen depletion 5

Principles of aeration 6

III. Types of pond aerators 6

Vertical pump aerators 7

Pump sprayer aerators 7

Propeller-aspirator pumps 8

Paddle wheel aerators 8

Diffused-air systems 9

IV. Use of aerators in ponds 10

Oxygen-transfer with aerators 10

Effects on production 10

Emergency aeration 11

Routine aeration 11

Aerator placement 12

V. Conclusion 13

VI. Additional assistance and information 13

REFERENCES 15

TABLE

Table 1 Measured Aerator Efficiencies 7

FIGURES

Figure 1 Generalized diurnal oxygen concentration fluctuation in a pond during a 24-hour period. 2

Figure 2 Portable dissolved oxygen meter. 4

Figure 3 General effects of DO concentrations (p/m) on fish metabolism, health, and survival. 5

Figure 4 Float-mounted vertical pump aerator in operation. 7

Figure 5 Pump sprayer aerator in operation. 8

Figure 6 Float-mounted electric propeller-aspirator aerator. 8

Figure 7 Electric paddle wheel aerator.. 8

Figure 8 Example diffuser with six individual silica air stones mounted on a bottom plate. 9

Figure 9 Heavy algae bloom in a pond. 11

Figure 10 Tractor driven emergency paddle wheel aerators. 11

Figure 11 Control box for DO meters. 12

Aeration of Ponds Used in Aquaculture

I. Introduction

The broad term "aquaculture" refers to the breeding, rearing, and harvesting of plants and animals in all types of water environments, including ponds, rivers, lakes, and the ocean. Similar to agriculture, aquaculture can take place in the natural environment or in an artificial setting. Using aquaculture techniques and technologies, researchers and the aquaculture industry are "growing," "producing," "culturing," and "farming" all types of freshwater and marine species. In the United States, a number of finfish, shellfish, and crustacean species are grown for commercial production of baitfish, recreational fisheries, food fish, and ornamental animals used in aquariums. The majority of freshwater aquaculture operations focus on species such as trout, salmon, bass, catfish, tilapia, prawns, carp, and mollusks.

The U.S. aquaculture industry experienced substantial growth in the past 15 years shown in both sales and the number of operations across the country. Between 1998 and 2005, annual sales from all types of aquaculture increased from about $978 million to almost $1.1 billion, and the number of farms increased from 4,028 to 4,309 (USDA 2005). The catfish industry is the largest sector in U.S. aquaculture, accounting for over 40 percent of all sales. Catfish production is concentrated in Mississippi, Alabama, Arkansas, and Louisiana.

Ponds are the most extensive aquaculture technology used in the United States. Active and proper pond management is essential to maintain maximum production levels and to ensure quality products. A host of management practices is necessary to address issues related to water quality, disease and pathogens, aquatic vegetation, sedimentation, and predator control. Managing dissolved oxygen (DO) levels in ponds is a major concern of pond managers because it typically involves the use of equipment that must either be built or purchased, often at considerable cost. Proper application of aeration technology requires a sound understanding of aeration principles commonly encountered under practical aquaculture conditions. Although natural pond dynamics attributable to biological and chemical processes produce the most DO to cultured organisms, conditions related to stocking density, season, and weather patterns can create the need for mechanical aeration (the process of adding oxygen to water to enhance productivity and survival).

This document presents practical information related to managing production through the use of aeration equipment in ponds used for aquaculture. In broad terms, this technical note discusses dissolved oxygen dynamics in ponds, types of pond aerators, and the use of aerators in ponds. Information synthesized and presented in this document reflects the state of the science at the time of publication.

II. Dissolved oxygen dynamics in ponds

DO is likely the most critical element of water quality in any aquaculture operation because all aerobic aquatic organisms need a constant supply of DO to survive. Consequently, a basic understanding of the mechanisms of oxygen production, transfer, and depletion is necessary to aid aquaculturists in the successful management of pond growing systems. Although some variables affecting DO dynamics are not easily influenced by pond managers, many factors can be manipulated to improve water quality conditions for successful production.

Sources of dissolved oxygen

The largest reservoir of oxygen in a natural setting is the atmosphere. Any given quantity of the air we breathe is composed of about 21 percent oxygen, 78 percent nitrogen, 0.9 percent argon, with the remainder containing a host of other, mostly inert, gases. Oxygen dissolves into water from two main sources: (1) the atmosphere, and (2) as a product of photosynthesis by aquatic plants, algae, and some bacteria.

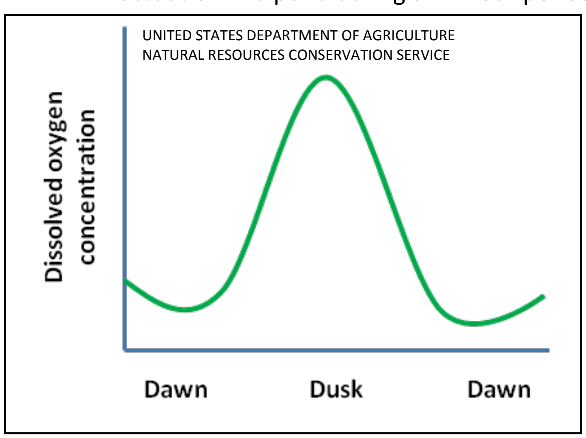
Atmospheric oxygen enters water by diffusion or turbulence associated with physical agitation of surface water. Direct diffusion is a very slow process because oxygen is only slightly soluble in water. Thus, surface agitation by wind or other means that mixes air and water together is the most effective way to add atmospheric oxygen into the water column. The process of mixing air with water to increase DO content is known as aeration.

Oxygen production by photosynthesis in aquatic plants and organisms is the primary source of DO in pond aquaculture systems. Photosynthesis in an aquaculture pond is fueled by light energy from the sun. Chlorophyll-bearing aquatic organisms like submergent and emergent plants, phytoplankton, and photosynthetic bacteria transfer oxygen into the water column as long as light is available.

Oxygen balance and stratification

Dissolved oxygen in pond water is depleted by diffusion back into the atmosphere, respiration in aquatic organisms and plants, and decomposition of organic material by microbes residing largely in bottom sediments. The amount of oxygen required for microbial activity is known as biochemical oxygen demand or BOD. On a daily basis, the amount of DO in a pond is highest during the day when photosynthesis is underway and lowest at night when respiration and BOD depletes oxygen. This largely predictable process, known as the diurnal oxygen cycle, is shown in Figure 1.

Figure 1 Generalized diurnal oxygen concentration fluctuation in a pond during a 24-hour period.



In a pond or lake not used for aquaculture, the supply of DO produced by photosynthesis or diffused from the atmosphere usually exceeds the amount required by respiration and BOD. However, the biomass of plants, animals, and microbes in an aquaculture pond is usually much higher than in natural waters, so oxygen is sometimes consumed faster than it is produced. Environmental factors, such as barometric pressure and altitude, can further affect DO balance in a pond, but temperature is likely the most influential variable. Warm water holds much less DO than cool water because the solubility of oxygen decreases with increasing temperature. In addition, increasing temperature accelerates other factors like respiration rates and BOD that remove DO from the water column (Boyd and Lichtkoppler 1979; Boyd 1998).

The upper layers of a pond absorb sunlight and heat, and the ability of light to penetrate into the water column decreases exponentially with depth. In addition, other factors like turbidity from suspended sediment or high algae concentrations further decrease the intensity of sunlight at depth. In a pond, the warmest water is found at the surface, and temperature generally decreases with depth. This layering of pond water, with less dense warm water "floating" on top of denser cold water, is known as thermal stratification. The degree to which a pond stratifies is largely driven by depth, surface area open to mixing by wind or mechanical means, and the relative biomass of plants and animals in the water column that might influence photosynthesis or decomposition rates (Hargreaves 2003). During the summer months, shallow aquaculture ponds (e.g., 3 to 8 feet deep) may stratify during the day and destratify or equalize water temperature from top to bottom by mixing at night. Ponds deeper than 10 feet may not fully mix during the night, causing the persistence of a layer of cold water with very low DO near the bottom.

Dissolved oxygen can also become stratified in a pond ecosystem, and the process and degree to which this occurs is closely tied to the same factors that drive thermal stratification dynamics. Increased sunlight intensity near the surface of the pond drives greater algal photosynthetic rates which increases DO concentration. Although oxygen can be produced deeper in the water column, BOD usually far exceeds production. Thus, surface water usually contains much more DO than water near the bottom of a pond. For example, on a calm, sunny summer afternoon, the DO concentration at the surface of a pond can be more than three times higher than the DO concentration along the bottom (Hargreaves 2003). The degree to which a pond exhibits oxygen (and temperature) stratification is correlated to depth; deeper ponds show greater differences in DO from top to bottom.

Dissolved oxygen concentration in the bottom of an aquaculture pond can be low enough to prevent aquatic animals from living in it. This poses an obvious problem for some cultured species, such as crayfish and prawns, that live on or near the bottom, but it is also a major issue for finfish that are forced to positions higher in the water column where mortality from disease, cannibalism, and predation from avian predators decreases production. Moreover, poor water quality factors like low DO concentration can limit yield as animals expend energy on survival instead of weight gain and growth.

Ponds at higher latitude and altitude

Ponds in the northern United States and at higher altitudes (3,000 feet and greater) have features that differentiate them from aquaculture ponds in southern climates. These differences, largely attributable to climate and pond size, affect DO dynamics during the growing season.

Aquaculture ponds at higher elevations or latitude may have smaller average surface areas (i.e., ¼ to 10 acres) and greater maximum depths (6 to 12 feet) than those in the Southern States (¼ to 50 acres and 3 to 8 feet, respectively). Greater depth and smaller surface area increases the likelihood that thermal stratification will occur during the summer, and the intensity of this stratification could result in the development of an anoxic (without DO) layer near the bottom of the pond.

Winter ice cover on a pond affects both physical and water quality elements in and around a pond. Ice development and movement can damage pond banks, floating and submerged equipment, and water control structures. Pond managers typically strive to keep pond surface area small in an attempt to combat icing effects in settings where carryover stocks are desired. Heavy ice and snow cover on ponds can block photosynthesis and result in oxygen depletion, although deeper ponds provide some buffer to extended periods of low DO that can result in mortality. In addition, vegetation that dies while ice covers ponds can deplete DO and affect water quality. Extended periods of snow cover on a pond can lead to high mortality, sometimes known as winterkill. In some cases, pond managers are forced to plow snow off of ponds so that light can penetrate and photosynthesis can take place. However, in some operations, winterkill may actually be planned for when holdover predators can decrease production. Finally, average annual air and water temperatures are lower at higher altitudes and latitudes. As previously discussed, this has a positive effect on DO concentrations, but the growing season is much shorter.

These physical and climate-related differences also affect management decisions associated with DO in higher latitude and altitude aquaculture ponds. Although DO may not be as significant of a concern in the summer months as in southern ponds, conditions in the Midwest can create low DO events. In addition, early season water temperature fluctuations can be significant, and overlap with the spawning and early life histories of species commonly cultured in northern latitude ponds (e.g., walleye and baitfish). Under these conditions, managing DO can be challenging, depending on daily weather, organic load in a pond, and the condition and composition of adjacent buffers and uplands.

Measuring dissolved oxygen

Monitoring the daily DO content of a fish pond is a common task for pond managers, especially in Southern States where oxygen depletion problems can affect productivity. Problems with DO levels can arise quickly and the response time for taking corrective measures can be very short. Consequently, aquaculturists need a rapid and reliable method of measuring DO concentrations to inform management actions.

A number of different methods exist for measuring DO concentrations in a fish pond, and several factors should be considered when selecting a tool or technique (Hargreaves and Tucker 2002). The number of ponds or tanks to be measured, desired level of accuracy, and cost of the tool or technique are three of the most commonly considered factors. Although the titrationbased "drop count" method is fairly rapid, it requires properly prepared chemical solutions and somewhat fragile equipment that may be difficult to use in a field situation. The drop count method is inexpensive, but likely only appropriate if DO concentration is measured infrequently in a few ponds or tanks. In most commercial fish farm settings or any other situation where DO measurement of multiple ponds or culture units is routine, a dissolved oxygen meter is an indispensable piece of equipment (Figure 2).

Figure 2 **Portable dissolved oxygen meter.** [1]

Most oxygen meters have 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. Circuitry within the meter compensates the reading for changes in temperature, altitude, or salinity, and may also include calibration features.

Oxygen sensors use technology that measures either ionic or optical reactions when a probe is immersed in water. Many different oxygen meters are commercially available, and each model has a unique combination of features that makes it more or less suitable for a particular application. 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 options for your area. Choosing a DO meter can be difficult, but Hargreaves and Tucker (2002) offer the following as desirable attributes:

- accuracy and ease of calibration
- rapid response
- water resistance and rugged construction
- automatic temperature compensation
- manual salinity and barometric pressure compensation
- 0 to 200 percent saturation measurement range
- easily changed cable or probe
- digital, back-lit liquid crystal display that can be read in bright sunlight or in total darkness
- an integral membrane cap assembly
- built-in calibration chamber and storage sleeve
- storage of measured values in memory within the meter (datalogging)
- a "hold" or "autoread" function indicating that a stable reading has been attained
- a battery charger

Operating a DO meter is best accomplished according to the instructions that come with a specific meter to ensure that the equipment is used within its operational range. Proper calibration is essential to ensure accuracy, and any DO meter must be appropriately maintained for reliable use.

DO concentrations for production

Managing an aquaculture pond for optimum production of shellfish, crustaceans, or finfish requires managing DO within a range of values that promote healthy, rapid growth. Dissolved oxygen levels in aquaculture ponds govern the metabolism and growth of aquatic organisms. Persistent low DO concentrations can significantly affect production because cultured species may consume less feed, grow more slowly, convert feed less efficiently, be more susceptible to infections, diseases, and even suffocate and die (Tucker 2005). Although DO concentrations differ spatially within an aquaculture pond, low DO can be pervasive because the

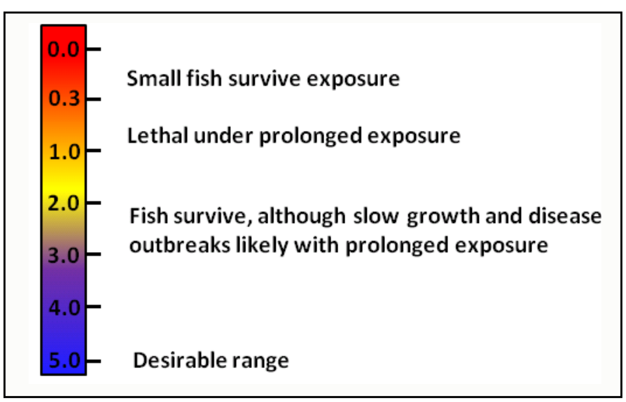
[1] *The use of trade and company names is solely for the benefit of illustrating a concept. Subsequent use does not constitute an official endorsement or approval of any service or product by the USDA NRCS to the exclusion of others that may be suitable.*

set of environmental conditions that promote oxygen depletion events usually exacerbate one another. For example, high water temperature increases metabolic rates in aquatic organisms, which increases respiration and depletes oxygen, especially on cloudy summer days that prevent photosynthetic organisms from producing oxygen. Similarly, if persistent low DO concentrations slow foraging behavior in cultured animals, uneaten feed and waste products fall to the bottom and fuel increased BOD that further removes oxygen from a pond.

Dissolved oxygen is measured in parts-per-million (p/m) or milligrams-per-liter (mg/L), and 5 p/m (5 mg/L) is like a single drop of food coloring in a 55-gallon barrel. Each species has slightly different DO requirements depending on developmental stage, water chemistry, and other environmental factors. Consequently, the following discussion is presented in general terms relevant to aquaculture operations. The reader is urged to seek additional information when species-specific DO requirements are relevant to aquaculture operations.

Swimming and feeding activities of most aquatic organisms are optimized when DO concentrations are greater than about 5 p/m (figure 3). Cold water fishes such as trout and salmon thrive at DO concentrations of 8 p/m or greater and actually stop swimming when DO drops below 4.5 p/m (Brett 1979). Conversely, tilapia, carp species, and catfish can tolerate DO concentrations between 1 and 2 p/m, although feed conversion and growth rates are depressed (Kutty 1968; Tucker and Hargreaves 2004; Hargreaves and Tomasso 2004).

Figure 3 General effects of DO concentrations (p/m) on fish metabolism, health, and survival.



Oxygen depletion

Oxygen depletion refers to factors that create low levels of DO leading to fish health problems and even mortality. As previously mentioned, DO concentrations of 5 p/m or greater are recommended for optimum aquatic organism health. Conversely, most fish are distressed when DO falls below 2 p/m. The number of fish that die during an oxygen depletion event is determined by the magnitude and duration of low DO values. In general, larger fish show adverse effects from low DO concentrations before smaller fish.

Most aquaculture ponds, except for those deeper than about 20 feet, mix or turnover naturally in the fall when air temperature cools and water in the pond is less intensely stratified. This mixing mechanism serves to roughly equalize DO and temperature gradients with depth in the pond. In general, strongly stratified ponds, or those where the temperature differential between surface and bottom layers is between 10 to 20 degrees, respectively, rarely mix fully without the assistance of outside forces that drive turnover. Strong winds, large precipitation events, or significant algal blooms can all disrupt stratified ponds, forcing deeper water with low DO concentration to rise above or combine with surface water. This scenario can have adverse consequences for cultured species, especially when turnover decreases DO concentration throughout the pond. Even minor oxygen depletion events can significantly impair the health and production levels of cultured species, and may result in severe mortality when worst-case variables are realized.

Critically low DO concentrations are common in aquaculture ponds during the growing season in the late evening and early morning (figure 1). Periodic monitoring of DO concentrations in aquaculture ponds is helpful in tracking conditions that may lead to oxygen depletion events. If equipment to test DO concentration is not available, the following observations and conditions can be used to anticipate oxygen depletion (Francis-Floyd 2003):

- fish swim at or near the surface gulping air (aka piping)
- fish suddenly stop feeding
- water color rapidly changes to brown, black or gray, signifying loss of an algal bloom
- putrid odor arises from the water

- extended period of hot, cloudy weather
- heavy summer wind, rainstorm, or both

These observations and conditions can occur alone or in interrelated combinations. Any one of the six conditions listed above indicates the need to adjust DO concentration in the water by any means available. In many aquaculture operations, mechanical aeration is a viable practice to employ when oxygen depletion occurs.

Principles of aeration

Aerating an aquaculture pond basically involves transferring gaseous oxygen from the large reservoir in the atmosphere into the waters of the pond where DO concentrations have dropped to critical levels. In general terms, the transfer rate of atmospheric oxygen into a pond depends on the amount of turbulence in the water, the ratio of the surface area of the pond to its volume, and how far the measured DO concentration deviates from the concentration at saturation (i.e., when the relative amount of oxygen in the atmosphere equals the DO concentration in water). The deviation between atmospheric oxygen and DO is called either the saturation deficit or surplus, depending on whether the measured DO concentration is below or above the saturation concentration. Saturation is influenced by a number of water quality parameters, especially salinity and temperature. In addition, oxygen is more easily dissolved in water at lower altitudes. For reference, in freshwater under atmospheric pressure at 20°C, oxygen saturation is about 9.1 p/m.

Oxygen moves into or out of water by diffusion, and the rate of diffusion depends on the difference in gas pressure between the liquid and gas phases. Oxygen moves faster from one phase to another when this difference is at a maximum. For example, atmospheric oxygen will readily diffuse into the surface layer of a pond with a DO concentration of 0 p/m. Aeration facilitates this transfer by increasing the amount of low DO content water exposed to air. In addition, if the thin film of water at a pond's surface is saturated with DO, diffusion of this supply of oxygen to deeper layers of the pond will be very slow without some form of agitation. Mixing by aeration restores or renews the saturation deficit in the surface film and increases the transfer rate of DO to deeper water.

Aeration improves other aspects of aquaculture pond environmental quality (Boyd 1998). Oxygenated water is distributed more evenly across a pond, so cultured species have more suitable habitat which decreases density factors and may improve growth. Aerators help to mix pond water which can reduce thermal stratification and improve other water chemistry factors, most notably DO content. Finally, mixing by aeration can minimize organic matter accumulation that may increase BOD, reduce the density of algal blooms that can lead to oxygen depletion and fish health issues, and shift the composition of algae blooms that may lead to flavor issues in finfish (Hargreaves 2003).

III. Types of pond aerators

There are various types of aerator configurations that can be used to increase DO concentrations in aquaculture ponds. Proper aeration system selection is based on several factors including the following:

- pond size
- pond depth
- pond shape
- power source availability
- aeration type (i.e., emergency or continuous)
- aerator efficiency
- seasonal changes (e.g., ice cover)
- fish harvest methodologies

Aerator performance is measured as either standard oxygen transfer rate (SOTR) or standard aeration efficiency (SAE). The SOTR is the amount of oxygen added to the water in 1 hour under standard conditions, expressed as pounds of O_2/hour. The SAE is the standard oxygen transfer rate divided by the horsepower (hp) of the unit, expressed as pounds of O_2/hp-hour transferred to the water. Table 1 provides data from Auburn University on measured aerator efficiencies (Boyd 1998). The average value, as well as, the range of values for each type of aerator is provided in the table. The range of values is a result of slight variation in design from different manufactures.

Table 1 Measured Aerator Efficiencies		
Aerator Type	**Average SAE (lbs 0_2/hp-hr)**	**SAE Range (lbs 0_2/hp-hr)**
Vertical pump	2.3	1.1 – 3.0
Pump sprayer	2.1	1.5 – 3.1
Propeller-aspirator pumps	2.6	2.1 – 3.0
Paddle wheels	3.6	1.8 – 4.9
Diffused air	1.5	1.1 – 2.0

Proper sizing and selection of an aeration system is critical to ensure that an adequate level of DO is achieved for the targeted organisms, while meeting the mobility and durability needs of the aquaculturist, and keeping energy consumption (i.e., operating costs) to a minimum. Oversized aeration systems can: (1) result in shoreline or pond bottom erosion, thereby increasing turbidity, (2) induce the suspension of waste products, organic detritus, or both on the pond bottom, (3) unnecessarily oversaturate the water, and (4) waste energy. These factors may ultimately have negative impacts on water quality and farm profitability. Advice on system size and placement can be obtained from other fish farmers, extension specialists, aquaculture supply companies, and aerator manufacturers.

More than one aerator unit may be needed to meet the management objectives of the aquaculturist because of spatial and temporal variations in DO concentrations within an aquaculture pond. When multiple units are deployed in a pond, it is important that they are positioned to work in concert with each other. The placement of individual and multiple aeration units is addressed in more detail in the following sections of this document.

Vertical pump aerators

Vertical pump aerators, also known as impeller aerators, consist of an electric motor with either a single or dual impeller attached to the motor shaft. Motors range in size from less than 0.5 hp to greater than 5 hp, with typical aquaculture units being 2 hp or less. Impeller design, combined with high shaft speeds of the motor (between 1,730 and 3,450 revolutions per minute (r/min)) throw pond water up into the air to increase gas transfer and induce surface disturbance (figure 4).

Figure 4 Float-mounted vertical pump aerator in operation.

Typically, the entire unit is suspended just below the surface of the water by a float. The float must have two anchor points to keep the unit in place and prevent rotation of the unit during operation. Anchor ropes or cables can extend to a weighted object on the pond bottom (such as a concrete block), or to a fixed point on the pond edge. Anchor ropes or cables that extend to the pond edge facilitate easier removal and installation of the unit if needed for maintenance or to remove or reposition the unit at harvest time.

Vertical pump aerators can also be mounted to a dock or other fixed feature, such as a pole embedded in the pond bottom or a tripod stand. Intake screens or cages are often installed on the units to prevent the uptake of debris and fish into the impeller housing. Minimum operating depths range from 21 to 48 inches depending on the size of the unit and the pumping efficiency. Some vertical pump aerators can be mounted so that the motor and impeller are fully submerged to reduce surface disturbance and act as a circulator.

Pump sprayer aerators

Pump sprayer aerators consist of high-pressure pumps powered by either a tractor power takeoff (PTO) or an electric motor, and function by pumping water under high pressure through one or more orifices into the air through pipes or manifolds (figure 5). These units can be operated in shallow depths, provided the intake for the pump is sufficiently submerged.

Figure 5 **Pump sprayer aerator in operation.**

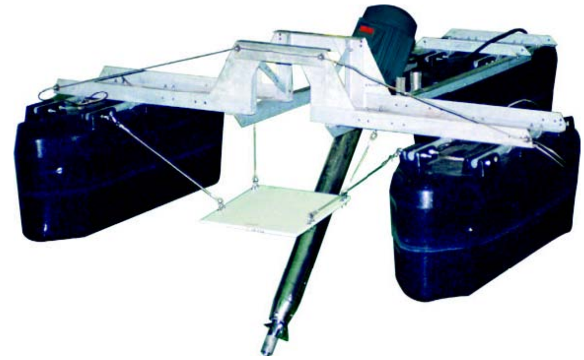
PTO-powered pump sprayer aerators are a popular choice for emergency aeration operations. They can be quickly moved from pond to pond and operated in shallow depths with little concern for suspension of pond bottom sediments and wastes.

Propeller-Aspirator Pumps

Propeller-aspirator pumps consist of a submerged impeller-diffuser mounted to a rotating shaft contained within a hollow housing. The rotating shaft is connected to an electric motor that spins the shaft at speeds of up to 3,450 rpm. The hollow housing allows air to be drawn down into the water column where it is mixed with the pond water as a result of the vacuum produced by the turbulence and water velocity created by the spinning impeller. Ambient air, which is drawn down the tube, enters the water column through the diffuser as fine bubbles where it is mixed by the impeller (Boyd 1998; Tucker 2005).

The unit is mounted to a float or system of floats, which allows adjustment of both the angle of the unit and the depth of the impeller (figure 6). Propeller-aspirator pumps can create significant circulation as well as aeration and are therefore more efficient in deeper ponds. Finally, screening considerations to prevent small-bodied fish from injury associated with spinning impellers should be considered where appropriate.

Figure 6 **Float-mounted electric propeller-aspirator aerator.** [1]



Paddle wheel aerators

Paddle wheel aerators consist of an arrangement of paddles attached to a rotating drum or shaft (figure 7). The pattern, length, and shape of the paddles affect the aeration efficiency of the unit. Paddle wheel aerator designs range from farm-manufactured units consisting of an automotive axle and differential with paddles welded to a wheel, to precisely machined and manufactured paddles attached in a spiral pattern around a drum.

Figure 7 **Electric paddle wheel aerator.**[1]

Typically, the paddles are 2 to 10 inches wide and are attached to a drum in an alternating or spiral pattern. Drum speeds range between 70 and 120 rpm, and the spinning paddles are typically submerged in 3 to 6 inches of pond water (Boyd 1998; Tucker 2005).

The SOTR of paddle wheel aerators can be improved by increasing paddle depth. However, additional load is placed on the motor, increasing energy consumption and resulting in a reduced SAE.

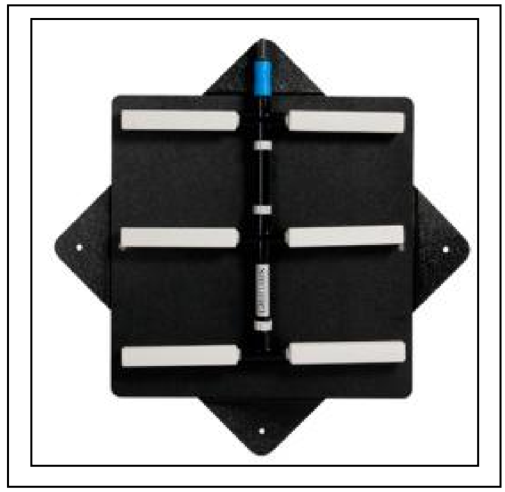
Paddle wheel aerators are very common in large ponds. The units are either powered by an electric motor or are trailer-mounted and powered by a tractor PTO. Electric-powered units are mounted to a float and are anchored to the pond edge. Although PTO units have a high SOTR, the SAE of electric units is much higher because much of the energy used in PTO units is consumed in operating the tractor engine and PTO drive train (Tucker 2005).

Similar to pump-sprayer aerators, paddle wheel aerators powered by a tractor PTO are often used for emergency aeration in larger ponds due to their mobility and high SOTR. However, PTO paddle wheels are often operated at shallow depths and have the potential to erode the pond bottom and increase turbidity. This can be minimized by either mounting a metal plate or similar structure to shield the pond bottom from the turbulence created by the paddle wheel, or by incorporating designated locations for the use of emergency aeration equipment into the pond design. In addition, incorporating erosion-resistant pond bottom materials can reduce suspension of sediments and organic material from paddle wheel aerators.

Diffused-air systems

Diffused-air systems use one or more regenerative blowers or rotary vane compressors to pump ambient air at low pressure and high volume to submerged diffusers. The most common diffusers are glass-bonded silica stones, however diffusers constructed of porous plastic, synthetic perforated membranes, and ceramic are also used (Boyd 1998; Tucker 2005). Diffusers can be various-sized rectangular or square stones, round or square disks, or elongated tubes and pipes (figure 8).

__Figure 8__ **Example diffuser with six individual silica air stones mounted on a bottom plate.**[1]



The efficiency of diffused-air systems is primarily a function of bubble size and diffuser depth. Diffusers that produce smaller bubbles, commonly referred to as fine-pore diffusers, are more efficient than diffusers that produce large or coarse bubbles. Smaller bubbles have more surface area relative to their volume, which facilitates more efficient oxygen transfer. In addition, when the bubbles are released at a greater depth, hydrostatic pressure from the water increases the DO saturation concentration, thereby increasing the saturation deficit (see section IV, below) when compared to surface water. Concurrently, deeper release points allow more contact time for the bubbles to diffuse oxygen into the water column as they rise to the surface (Boyd 1998; Tucker 2005).

Placing diffuser stones above the bottom of the pond helps minimize suspension of bottom sediments. Diffuser depth also has an impact on water circulation rates within the pond. As the bubbles rise to the surface and expand, water is entrained. This process creates an air-lift, which pumps the bubbles and entrained water to the surface. Deeper water is typically cooler and denser than the surface water and slowly spreads out and away from the rising column of bubbles, creating vertical circulation between the pond bottom and the surface. This circulation cell has a limited horizontal extent and, therefore, diffused aeration systems usually require several diffusers arranged in a grid pattern to effectively aerate and circulate the impoundment.

Subsequently, diffused aeration systems are more effective in deeper ponds (greater than 10 feet) and are less common in intensive commercial aquaculture impoundments as a result of the air delivery system tubing and its interference with seine harvesting. Diffused air systems are much more common in tank or raceway culture units.

IV. Use of aerators in ponds

Oxygen transfer with aerators

The driving force causing oxygen to enter water from the atmosphere and increase the DO in the water is the saturation deficit. Saturation deficit is the difference between the oxygen pressure in the water and the oxygen pressure in the air. This difference is greatest when the water has no DO (like deep well water). The oxygen transfer rate into the water is fastest when the saturation deficit is high and will slow as the deficit decreases and approaches the saturation level. Aeration increases the surface area of the pond water in contact with the atmosphere and thereby increases the oxygen transfer rate. Oxygen can enter the water during the daylight hours as a byproduct of the photosynthetic process of algae and other aquatic organisms.

In ponds with DO below saturation, aerators can be used to transfer oxygen by exposing more water surface to the atmosphere by mechanical agitation (bubbling, splashing, etc.). Aerators that stir or mix the pond can also increase DO by moving surface water with higher DO to other places within the water body. Aerators with a combination of splashing and rotational movement like a paddle wheel actually create a current in the pond that attracts fish to more oxygenated water near the paddle wheel.

In an aquaculture pond, DO is usually above saturation during the day because of the oxygen produced by photosynthesis. Therefore, aerators that splash water into the air are usually not necessary during the day. At night, aquatic organisms and BOD consumes DO in the water, leading to oxygen depletion. In this case, aerators are often used at night or during extended periods of cloudy weather to increase DO levels until photosynthesis replenishes the water column.

Effects on production

Stress on aquacultural organisms is detrimental to production, and low DO levels are often a primary stressor. Also, stressed fish often are more susceptible to disease, which may lead to decreased growth rates and mortality. Stressed aquaculture species often feed less, and uneaten feed can sink to the pond bottom where it is consumed by organisms that decrease DO by increasing BOD. These factors can combine to deplete DO in a pond, and aeration is commonly used to increase DO levels and improve water quality and productivity.

Modern aquaculture experience suggests that about 2,000 kilograms (kg) per hectare (ha) (1,786 pounds (lbs) per acre (a)) of most species of shrimp and fish can be produced in ponds without aeration. With proper aeration, it is reasonable to expect a production of up to 6,000 kg/ha (5,357 lbs/a). Tilapia are a species that can tolerate low DO with production in excess of 5,000 kg/ha (4,464 lbs/a) in unaerated ponds. Practical experience by commercial channel catfish producers indicate that about 11,200 to 16,800 kg/ha (10,000 to 15,000 lbs/a) usually is the maximum production possible in static water ponds (Boyd, personal communication, 05/09/2011).

Daily feeding rates during peak production periods are also associated with the need for pond aeration. Experience with channel catfish production in the Southern United States suggests that at feeding rates below 30 kg/ha/day (26.8 lbs/a/day), aeration usually will not be necessary and annual production of 2,000 to 3,000 kg/ha (1,786 to 2,679 lbs/a) can be achieved. At feeding rates between 30 and 50 kg/ha/day (26.8 to 44.6 lbs/a/day), emergency aeration must be applied occasionally to most ponds or low DO concentrations will cause stress or mortality. In this range of feeding rates, an annual production of 3,000 to 4,500 kg/ha (2,679 to 4,018 lb/a) of catfish is normal. Where feeding rates exceed 50 to 60 kg/ha/day (44.6 to 53.6 lbs/a/day), aeration will be necessary in nearly all ponds during warm weather, especially during some of the nighttime hours (Boyd 1998). At extreme stocking rates, routine nightly aeration will usually produce more catfish at a better feed conversion than utilizing emergency aeration procedures (Lai-fa and Boyd, 1989).

One would think that pond production is limitless with enough aeration. However, production cannot be increased without limit because high ammonia concentrations produced as metabolic waste will impose production limits, and density factors can increase disease rates and may produce behavioral problems in cultured species.

Emergency aeration

Algae in a pond are natural. In an aquaculture pond where nutrients are plentiful, algae will often make the water appear green. Algae can sometimes explode into what is known as a "heavy bloom," often visible on the surface of the pond (figure 9). When algal biomass is extensive, a large portion of the population is continually dying and decaying, which consumes oxygen in the water (BOD). Emergency aeration is critical when algae are consuming excessive amounts of oxygen or when the entire algae population suddenly dies for some reason. Complete algae dieoffs can often be attributed to quick changes in the environment such as sudden cooler weather, significant rainfall that cools the pond, or extended lack of sunshine. Mechanical emergency aeration must often continue in an aquaculture operation until the algae population stabilizes. PTO driven paddle wheel aerators are often the choice for emergency situations in large aquaculture operations (figure 10). These aerators are mobile and can quickly raise DO concentrations. They do not require an electrical service but do require a large tractor to operate.

Figure 9 **Heavy algae bloom in a pond.**

Figure 10 **Tractor-driven emergency paddle wheel aerators.**

When aquaculture is semi-intense (average stocking rates), DO can often be monitored and aeration only used as an emergency situation when needed. An intense aquaculture system (high stocking rates) should never rely on just emergency aeration and should use aeration as a more routine management practice.

Routine aeration

It is well understood that in aquacultural systems that push the limit on production, routine aeration must be used. Moderate routine aeration that improves water quality and enhances feed conversion is often more profitable than emergency aeration. In intense aquaculture, aeration is often applied each night or continuously, especially when stocking rates are kept near maximum levels for a given pond.

Water circulation with routine aeration in ponds has proven to be beneficial by preventing thermal and chemical stratification of the water column. Proper water circulation can make the entire pond more habitable and often minimizes the danger of overturns in deep ponds. Circulation may also stimulate phytoplankton growth by balancing the distribution of organisms within a pond (Saneres, et al. 1986). Water movement created by an aerator helps maintain high oxygen transfer efficiency because the freshly oxygenated water is propelled away from the aerator and replaced by water of lower DO concentration.

The question often confronting aquaculture farmers who utilize routine aeration is when to power on the aerators. Catfish farmers in the Southern United States often check pond DO level at dusk and frequently during the night. Super saturation in late afternoon can signal problems with low DO the following morning as high photosynthesis rates cease and respiration takes over. Periodically monitoring DO dynamics can provide insight into the timing of low DO levels and may allow prediction of when daily oxygen depletion events occur and when aeration is needed. Timers can also be used to control aerators when daily DO cycles are known, commonly between dusk and dawn. In addition, DO monitoring equipment is becoming more complex and reliable, often includes features that can also be used to power aerators on and off, and can include cell phone notification to the farmer (figure 11).

Figure 11 Control box for DO meters.[1]

Aerator placement

Another factor that influences the effectiveness of an aeration system is the placement of the aerators within the pond, relative to both the type of aerator used as well as the need for aeration. All aerators provide some level of water circulation within the pond. Depending on the type of aerator, this circulation can be primarily oriented horizontally or vertically to the pond surface.

If the long axis of a pond is oriented along the direction of prevailing winds, locating aerators to take advantage of wind-driven currents will help to distribute oxygenated water and will improve circulation and transfer efficiency. These factors will produce the most effective circulation in the pond and promote optimum water quality and production conditions. When several aerators are used in a pond, it is best to locate the equipment so that they work with, rather than against each other in producing current. Locating several aerators in a pond should be done according to site factors such as depth, direction of prevailing winds, proximity to electrical power sources, and accessibility for fueling and maintaining the equipment.

Typical PTO-powered aerators, which are more commonly used for emergency use, should be located in an area where the tractor can be safely positioned and there is suitable access to the pond. PTO-driven paddle wheel aerators are used in shallow depths and can create strong currents that erode the pond bottom and increase turbidity. The erosion can be significant enough where the aerator actually sinks into the scour hole created by the aerator, which may reduce aeration efficiency and place additional load on the tractor, aerator components, and drive train. PTO-powered units should be operated in designated areas within the pond where erosion-resistant materials have been incorporated into the pond bottom.

Paddle wheel and pump aspirator aerators create strong horizontal circulation currents. The angle of propeller-aspirator pumps can be adjusted to change the degree of circulation in the horizontal or vertical direction. When only one of the above-referenced units is deployed, the best place to operate the unit is at the middle of the long axis of the pond with the current directed across the short axis of the pond (Tucker 2005). When multiple units are deployed they can be located in the same orientation to produce several circulation cells within the pond. Conversely, they can be positioned around the perimeter of the pond with the current directed parallel to the shoreline to create one large circulation cell in the pond (Tucker 2005). The circulation of water around the perimeter of the pond can induce erosion around the pond perimeter and deposition of material near the pond center.

Consequently, this factor should be accounted for when sizing and locating aerators.

Vertical pump aerators and diffused-air systems create strong vertical circulation cells within the pond. Diffused-air systems should be located in the deepest part of the pond to induce the greatest amount of circulation and provide the longest contact time for the bubbles with the water column to facilitate oxygen transfer. Float-mounted vertical pump aerators are often located in the middle of the pond, however final positioning is a function of pond size. Multiple vertical circulation cells that radiate outward from the aerator actually move wastes and debris along the pond bottom toward the aerator as water moves toward its intake. If the aerator is sized correctly for the pond, circulation cells can create a small dead zone directly beneath the aerator where negatively buoyant wastes and debris settle. This collection point can assist the aquaculturist in the periodic removal of wastes from the pond environment.

In northern climates, where ponds are commonly used for trout production, vertical pump aerators may be operated continuously during the winter months to discourage ice formation on the pond surface. Under this scenario, proximity to inflowing water or proximity to automatic feeders may influence aerator placement.

Aerators can also be used to minimize dead areas (areas with no circulation) in shallow ponds used for crawfish or shrimp production. If the aerators are used in conjunction with baffles in the pond, the dead areas can be almost totally eliminated (Lawson and Wheaton 1983).

V. Conclusion

Using aeration equipment to increase productivity in aquaculture ponds is often a critical management activity. This document provides current information regarding dissolved oxygen dynamics in ponds, types of pond aerators, and the use of aerators in ponds. Although efforts have been made to provide information that covers a broad range of aquaculture activities, regional differences in climate, water quality, geography, and cultured species often present unique management challenges that require more specialized information.

VI. Additional assistance and information

Assistance on aquaculture topics is available from the NRCS at the regional, State, and field office levels, from State Cooperative Extension System offices, and from five regional aquaculture centers (RACs) established by Congress in title XIV of the Agriculture & Food Act of 1980, and the Food Security Act of 1985 (subtitle L, section 1475[d]). The RACs encourage cooperative and collaborative research and extension education programs in aquaculture having regional or national application. The mission of the centers is to support aquaculture research, development, demonstration, and education to enhance viable and profitable U.S. aquaculture production to benefit consumers, producers, service industries, and the American economy. Projects that are developed and funded by the RACs are based on industry needs and are designed to directly impact commercial aquaculture development in all States and territories. The RACs are organized to take advantage of the best aquaculture science, education skills, and facilities in the United States. Regional aquaculture center programs ensure effective coordination and a regionwide team approach to projects jointly conducted by research, extension, Government, and industry personnel.

Contact information for NRCS offices and personnel, as well as RACs is presented below. State or regional cooperative extension specialists at the local level should also be contacted. The reader is encouraged to get in touch with resource professionals as identified below with questions regarding pond aeration and other issues associated with commercial aquaculture.

NRCS office locator:
http://www.nrcs.usda.gov/contact/

Cooperative Extension System offices:
http://www.csrees.usda.gov/Extension/

Center for Tropical and Subtropical Aquaculture
(American Samoa, Commonwealth of the Northern Mariana Islands, Guam, Hawaii, Republic of the Marshall Islands, Federated States of Micronesia, and Palau):
http://www.ctsa.org/

Southern Regional Aquaculture Center (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas, U.S. Virgin Islands, and Virginia): http://srac.msstate.edu

Northeastern Regional Aquaculture Center (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia, and the District of Columbia): http://www.nrac.umd.edu/

Western Regional Aquaculture Center (Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Washington, Wyoming, and Utah): http://www.fish.washington.edu/wrac/

North Central Regional Aquaculture Center (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin): http://www.ncrac.org/

REFERENCES

Boyd, C.E. and F. Lichtkoppler. 1979. Water Quality Management in Pond Fish Culture. Research and Development Series No. 22, International Center for Aquaculture, Agricultural Experiment Station, Auburn University, Auburn, Alabama.

Boyd, C.E. 1998. Pond Water Aeration Systems. Department of Fisheries and Allied Aquacultures, Auburn University, Auburn, Alabama, Vol. 18, Issue 1, Pages 9-40.

Brett, J.R. 1979. Environmental Factors and Growth. In: W. S. Hoar, D. J. Randall, and J. R. Brett (Eds.), Fish Physiology. Vol. 8. ed. Academic Press, London and New York, pp. 599 – 675.

Francis-Floyd, R. 2003. Dissolved Oxygen for Fish Production. Fact Sheet FA-27. Department of Fisheries and Aquatic Sciences, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida.

Hargreaves, J.A. and C.S. Tucker. 2002. Measuring Dissolved Oxygen Concentration in Aquaculture. Southern Regional Aquaculture Center, SRAC Publication No. 4601. United States Department of Agriculture, Cooperative State Research, Education, and Extension Service. Mississippi State University, Mississippi State, Mississippi.

Hargreaves, J.A. 2003. Pond Mixing. Southern Regional Aquaculture Center, SRAC Publication No. 4602, United States Department of Agriculture, Cooperative State Research, Education, and Extension Service. Mississippi State University, Mississippi State, Mississippi.

Hargreaves, J.A. and J.R. Tomasso, Jr. 2004. Environmental Biology. In C.S. Tucker and J.A. Hargreaves (Eds.), Biology and Culture of Channel Catfish, Elsevier B.V., Amsterdam Netherlands, Pages 36-68.

Kutty, M.N. 1968. Influence of Ambient Oxygen on the Swimming Performance of Goldfish and Rainbow Trout. Can. J, Zool, 46:647– 653.

Lai-fa, Z., and C.E. Boyd. 1989. Nightly Aeration to Increase the Efficiency of Channel Catfish Production. Prog. Fish-Cult. 50, 237–242.

Lawson, T.B. and Wheaton, F.W. 1983. Crawfish Culture Systems and Their Management, J. World Maric. Soc. 14, 325–335.

Sanares, R.C., S.A. Katase, A.W. Fast, and K.E. Carpenter. 1986. Water Dynamics in Brackishwater Shrimp Ponds with Artificial Aeration and Circulation. In: Maclean, J.L., Dizon, L.B., Hosillos, L.V. (Eds.), The First Asian Fisheries Forum, Asian Fisheries Society, Manila, Philippines, ISBN 971-1022-27, Page 83–86.

Tucker, C.S. and J. A. Hargreaves. 2004. Pond Water Quality." In C.S. Tucker and J.A. Hargreaves (Eds.), Biology and Culture of Channel Catfish, Elsevier B.V., Amsterdam Netherlands, pp. 215-273.

Tucker, C.S. 2005. Pond Aeration. Southern Regional Aquaculture Center, SRAC Publication No. 3700. United States Department of Agriculture, Cooperative State Research, Education, and Extension Service. Mississippi State University, Mississippi State, Mississippi.

United States Department of Agriculture (USDA) 2005. Census of Aquaculture, Volume 3, Special Studies, Part 2. USDA-National Agricultural Statistics Service, AC-02-SP-2. Washington, DC.