United States Department of Agriculture
Soil Conservation Service
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ENGINEERING - AGRICULTURAL ENGINEERING NOTE-3, 210-VI

SUBJECT: ENG - AERATION OF PONDS USED IN AQUACULTURE

Purpose. To distribute Agricultural Engineering Note 3, "Aeration of Ponds Used in Aquaculture."

Effective Date. Effective when received.

Background. Agricultural Engineering Note-3 was developed to provide guidance and information to the Soil Conservation Service field staffs in the above subject.

Filing Instructions. Agricultural Engineering Note-3 should be filed with other Agricultural Engineering Notes under Title 210 of the directives system.

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Enclosure

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U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Agricultural Engineering Note 3

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REMARKS

United States
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Note 3

Aeration of Ponds Used in Aquaculture

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TABLES AND ILLUSTRATIONS

AERATION OF PONDS USED IN AQUACULTURE

Commercial aquaculture, or fish farming, is an important agricultural industry in the United States. Beginning during the seventies and continuing into the eighties, the industry has grown at a spectacular rate. The Soil Conservation Service provides technical assistance in assessing resources and in planning, designing, and installing ponds, raceways, and other facilities. This technical assistance includes recommendations for aeration to increase yields of fish and to ensure their survival. Aeration, the addition of oxygen to water, is widely used in aquaculture. It is necessary where fish are cultured at high densities in raceways, tanks, silos, or other small areas. Occasionally, emergency aeration is needed in ponds.

This Engineering Note (a) presents the requirements for dissolved oxygen by the species of fish cultured, (b) reviews some of the dynamics of pond culture that affect concentrations of dissolved oxygen, and (c) examines the methods used to correct or prevent inadequate levels of dissolved oxygen in ponds.

Aeration of raceways for cool water species is not discussed in this engineering note. In raceways installed primarily for trout and other cool-water species, aerators are customarily built in during the construction of the raceway. The physiological requirements of cool-water species are much more demanding than are those of channel catfish. In the cooler waters of the northern states, a chemical and biological analysis should be conducted by a qualified specialist before a recommendation for aeration is made. This is especially true in trout culture systems. Aeration tends to warm water and cause stress as the upper limit of favorable temperature is reached. There are also other chemical and biological factors associated with aeration that cause stress.

Producers of warm-water species are using various types of equipment that move the water and prevent thermal and oxygen stratification. In systems for catfish, crawfish, and nearly all other species that benefit from water movement, stocking densities and feeding rates can be slightly higher if these devices are used. However, an emergency system should be available to aerate the ponds quickly when dissolved oxygen content approaches the critical level.

Requirements for Dissolved Oxygen

Dissolved oxygen is a critical factor in fish culture. Table 1 shows the minimum and optimum levels of dissolved oxygen for the more common species cultured. When content of dissolved oxygen drops to about 2 parts per million (ppm), fish will die if exposure is prolonged. Between 2 to 5 ppm, fish will survive, but will grow slowly if exposure is prolonged and will become more susceptible to parasites and diseases (fig. 1).

Table 1. - Minimum and optimum levels of dissolved oxygen for the culture of various species of fish

Dissolved Oxygen Level	Species				
	Trout	Catfish	Crawfish	Bait Minnows	Freshwater Prawn
	ppm				
Desirable	8 or more	5 or more	5	5	5
Minimum	5	3	3	3	3

The critical level, the point where emergency aeration should be started, for warm-water species is generally considered about 2 ppm.

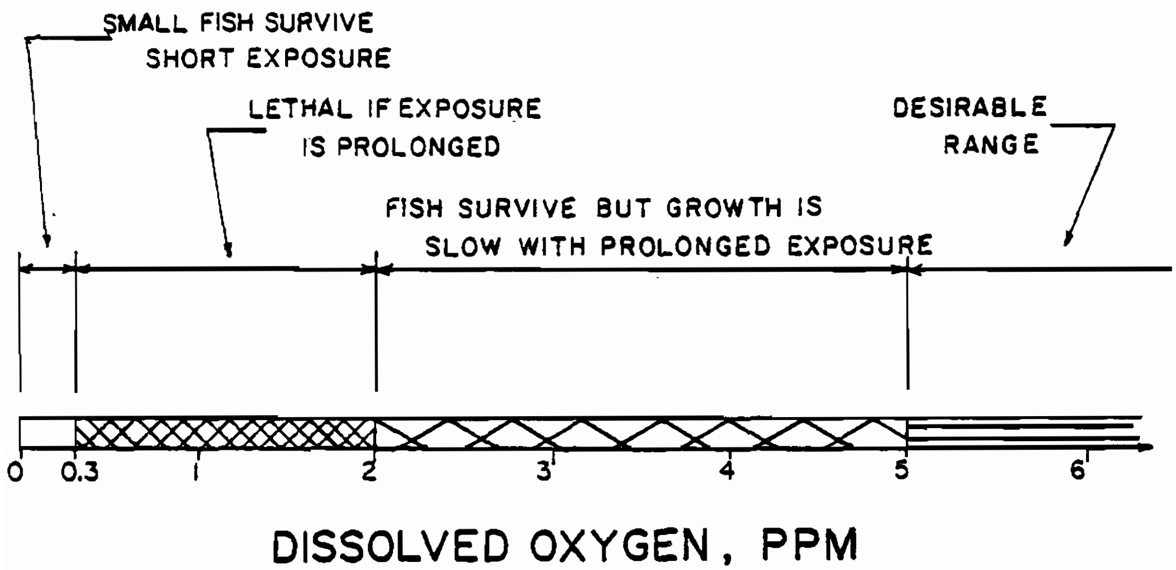

Figure 1. - Effects of dissolved oxygen concentrations.

Dynamics of Pond Culture and Dissolved Oxygen

Sources of Dissolved Oxygen

The two major sources of oxygen in water are plants in which photosynthesis occurs and the atmosphere.

Atmospheric Oxygen.--The atmosphere is about 21 percent oxygen. Cold water [near 0°C (32°F)] when thoroughly saturated in contact with the atmosphere at sea level contains about 15 ppm of oxygen. Oxygen content drops as temperature, elevation, or salinity increases or as barometric pressure decreases. For instance, a water sample that is 25°C (77°F) with a salinity of 5 parts per thousand taken from a site that is 300 m (1,000 ft) above sea level would contain only 8.0 to 8.2 ppm of oxygen when fully saturated.

The rate at which oxygen transfers from the air to water depends on water temperature, salinity, degree of saturation of the water, and turbulence at the surface. Turbulence at the surface increases the area of contact between air and water. The greater the air-water interface area, the greater the transfer. The rate of transfer is rapid when transfer begins and decreases as saturation is approached. In equation form, the oxygen transfer relationship can be expressed as:

$$\frac{dc}{dt} = K_La\ (Cs - Ce)$$

Where $\frac{dc}{dt}$ is the rate of change of oxygen concentration with respect to time

K_La is the overall oxygen transfer coefficient
Cs is the saturation concentration of oxygen in the liquid, and
Ce is the oxygen concentration in the liquid.

Even though dissolved oxygen will diffuse into water, its rate of diffusion is slow. Therefore, photosynthesis is the primary natural source of dissolved oxygen in a pond.

Photosynthesis.--Photosynthesis occurs only in the presence of light. The same plants that release oxygen during the daylight hours require an oxygen supply during periods of darkness. Production of oxygen by photosynthesis lags slightly behind the daily radiant energy cycle. The oxygen content of natural and man-made pond waters usually is highest in the mid to late afternoon and lowest just at or slightly after daybreak (fig. 2). Therefore, the manager of an aquacultural enterprise should check his ponds at or before daybreak for dissolved oxygen.

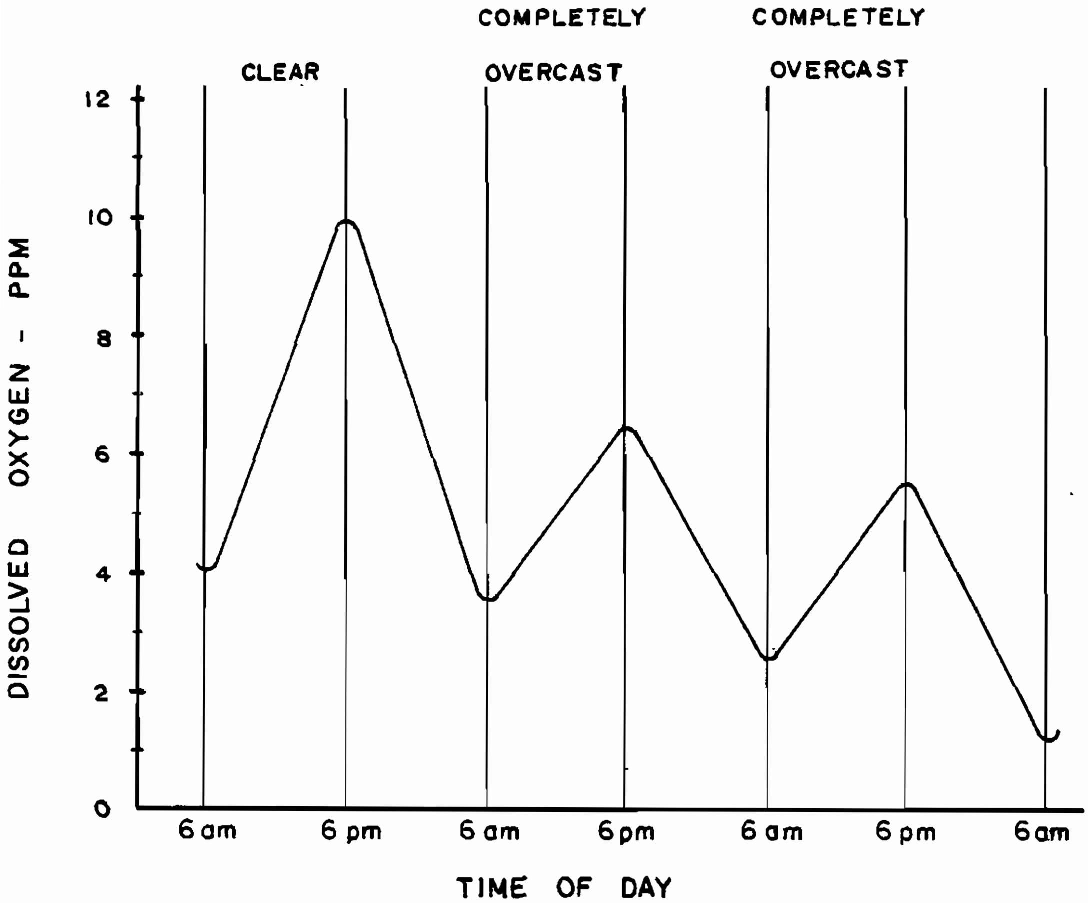

Figure 2.--Relation of dissolved oxygen concentration to time of day.

Oxygen Stratification in Ponds

Water at the surface of a pond is supersaturated with dissolved oxygen. Oxygen content decreases rapidly below a depth of 1 m (3 ft). Oxygen production decreases with pond depth because the intensity of light diminishes as the light passes through water. No oxygen is produced below the limit of light penetration. The upper layer of water, called the epilimnion, is normally rich in oxygen; the water below this layer, called the hypolimnion, contains little dissolved oxygen (fig. 3). This chemical stratification, or distinct change in oxygen content, may correspond closely to thermal stratification.

Winds or heavy cold rains may break up thermal stratification in ponds, causing complete mixing (turnover) of the anoxic water in the hypolimnion and the oxygenated water in the epilimnion. In deeper, embankment-type ponds that contain a large volume of anoxic water, oxygen depletion may result.

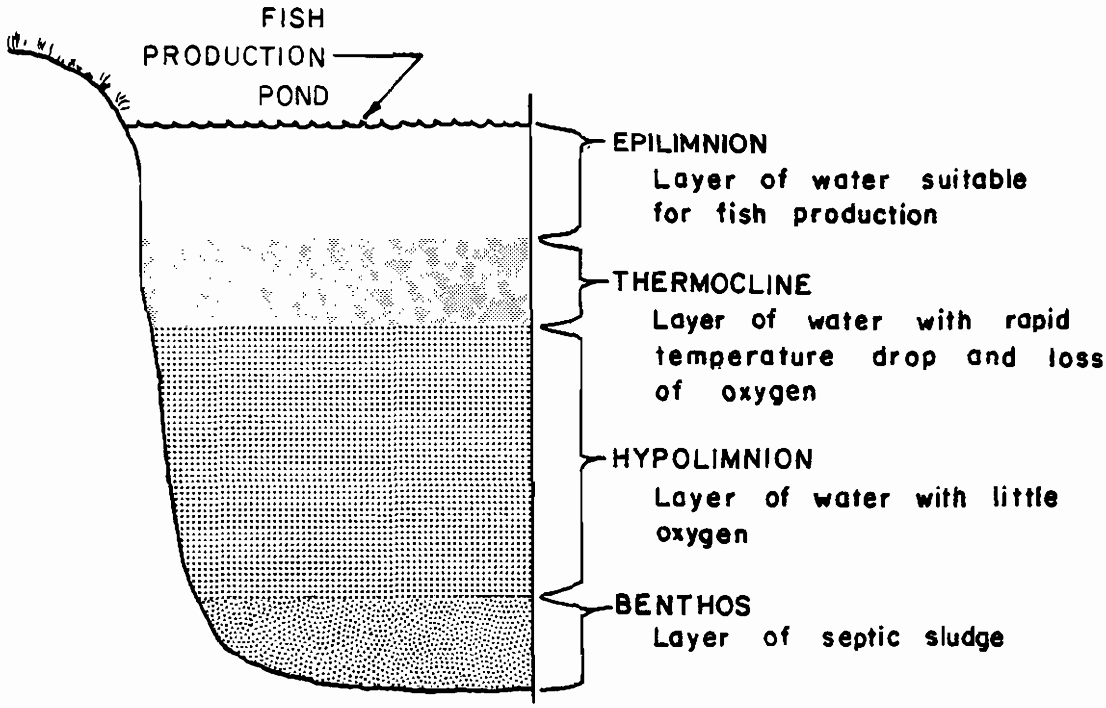

Figure 3. -- Pond stratification.

Removal of Oxygen from Ponds

Dissolved oxygen is removed from pond waters through respiration by plankton (phytoplankton included), fishes, and benthic organisms (those living in or attached to the mud) and by diffusion of oxygen into the air. Atmospheric oxygen diffuses into ponds only when waters are below saturation. Diffusion out of ponds occurs only when waters are supersaturated. In northern climates, oxygen levels are often low in winter when pond surfaces are frozen.

Sometimes dissolved oxygen is consumed faster than it is replaced. Some reasons for that are excess growth and decay of plankton, the biological oxygen demand (BOD) created by daily supplemental feeding, and the metabolism of fish if population densities are high.

Providing Adequate Concentrations of Dissolved Oxygen

Predicting Critical Oxygen Levels

During periods when oxygen levels are expected to be low, fish culturists can monitor dissolved oxygen concentrations during the night to determine if emergency aeration is needed. Procedures have recently been developed for predicting the low to which the concentration of dissolved oxygen will drop during the night. The simplest of these procedures involves measuring dissolved oxygen concentrations at dusk and again 2 or 3 hours later. These two values are plotted versus time on a graph, and a straight line is drawn through the two points (fig. 4). The point where the extension of this line crosses the horizontal line representing the critical level indicates when the critical threshold will be reached. If the projection indicates that the dissolved oxygen concentration will reach the critical level long before dawn, emergency aeration will be needed to prevent severe oxygen depletion. This procedure is a helpful management tool, but it is not 100 percent reliable because plankton die-offs can cause sudden, unpredictable oxygen depletions.

Emergency Aeration Procedures

A number of procedures are used to prevent fish kills when dissolved oxygen concentrations are dangerously low. Not all are effective. The use of potassium permanganate and calcium hydroxide has been recommended by researchers. Recent research, however, has demonstrated that potassium permanganate is worthless for this purpose and may even increase the time required for dissolved oxygen concentrations to return to normal levels. Calcium hydroxide is effective only in removing carbon dioxide so that fish can better

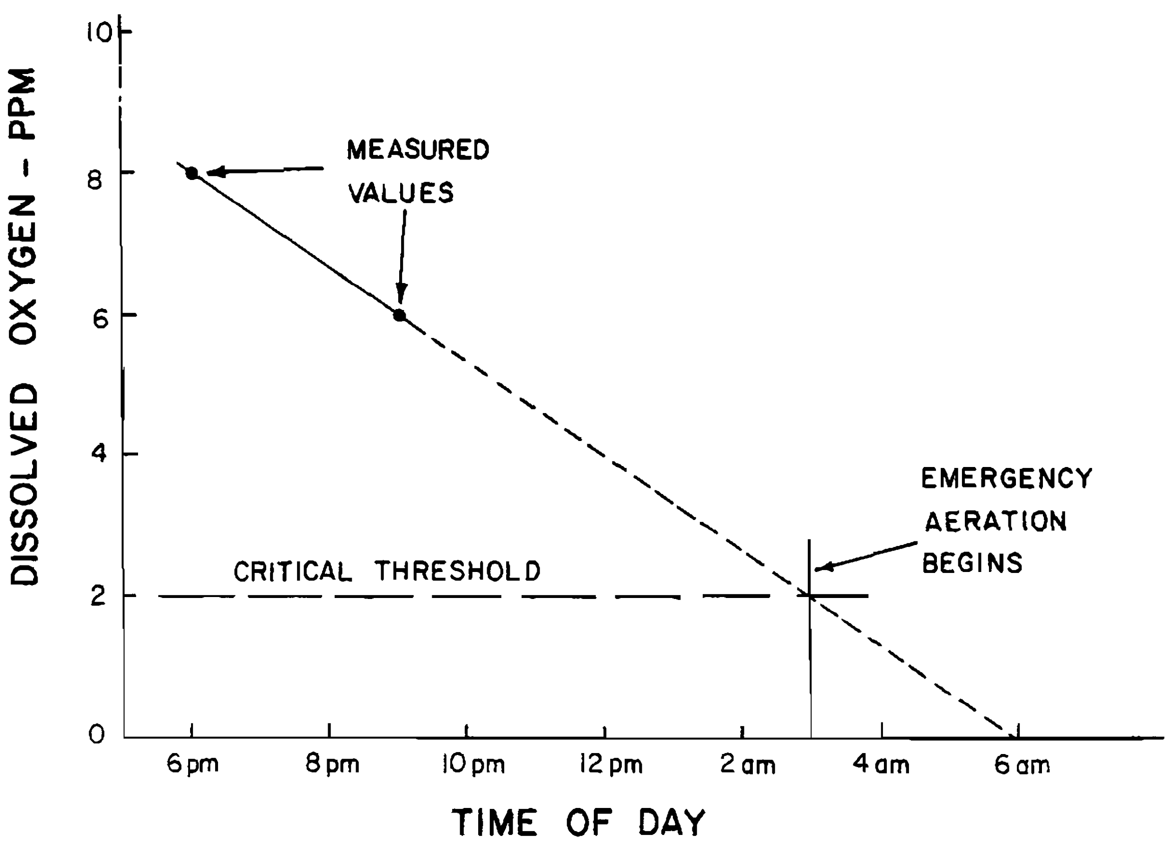

Figure 4.--A method of predicting the nighttime decline in dissolved oxygen concentration.

utilize the low concentration of dissolved oxygen. Following phytoplankton die-offs, applications of fertilizers have been used to stimulate new phytoplankton growth. There is no completed research to evaluate the effectiveness of this practice. It is doubtful that fertilization is necessary, however, because nutrient levels are already quite high in most commercial operations.

The only really effective way to prevent fish mortality when concentrations of dissolved oxygen are extremely low is to use mechanical devices. Large tractor-powered pumps may be used to pump fresh, oxygenated water from a nearby source into a pond that is low in oxygen.

Where water is pumped into a pond from a source with a low concentration of dissolved oxygen, a splash box at the point of discharge can be used to oxygenate the water and release harmful gases (fig. 5). Splash boxes are framed rectangular structures with one or

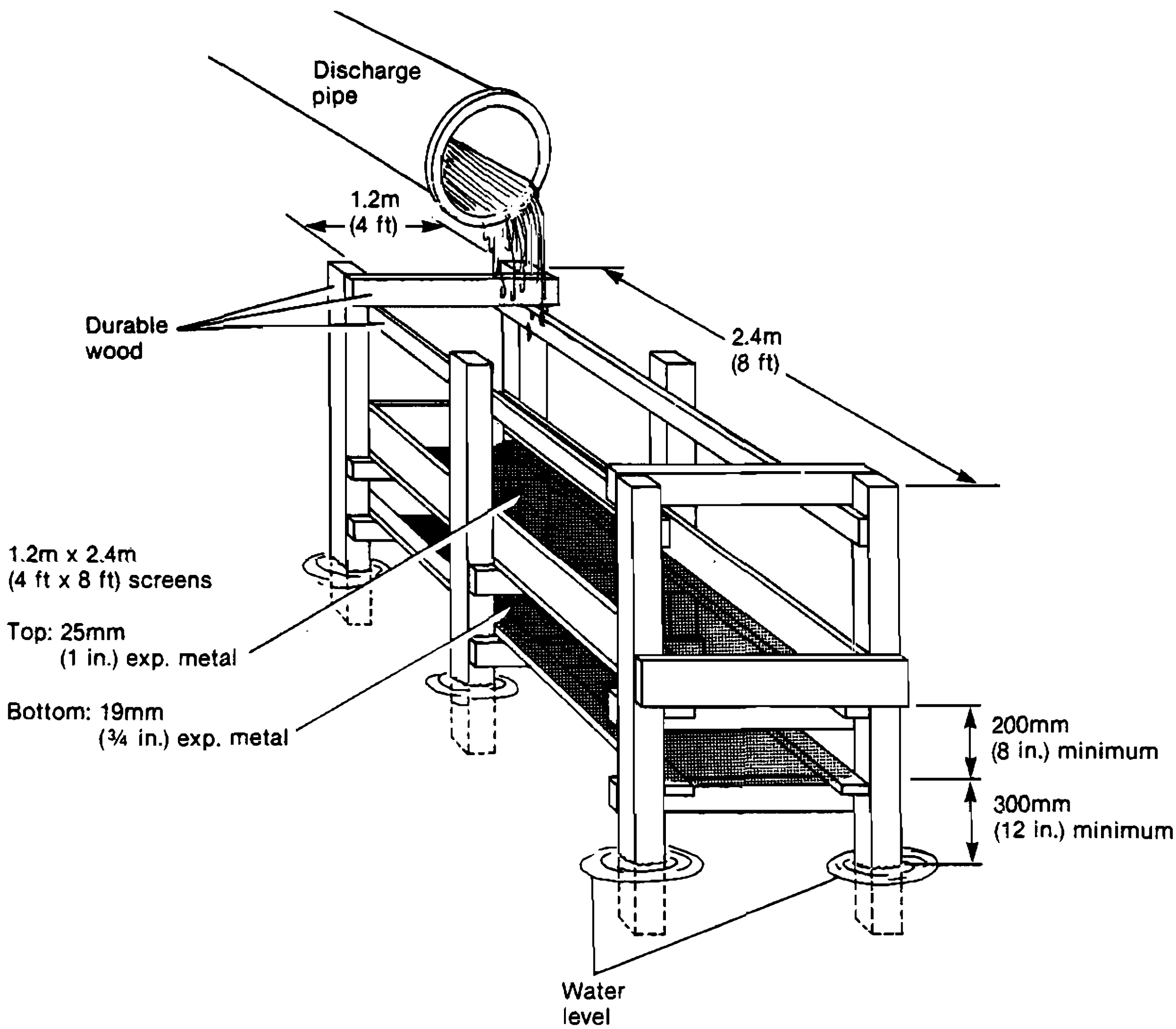

Figure 5.--Rectangular framed splash box.

two levels of expanded metal or perforated screens. Excess nitrogen can be driven off during aeration. Well water should be discharged across a baffle for aeration before entering the pond because most well water is low in dissolved oxygen and high in carbon dioxide. Another device used to oxygenate water from wells is an alfalfa valve, which creates a fan-shaped pattern when fastened to the end of the discharge pipe.

Pumps are also used to recirculate the water in a pond by drawing water from a depth of 0.6 to 0.9 m (2 to 3 ft) below the pond surface, where the dissolved oxygen level is low, and discharging it into the air above the pond or into a splash box. This adds dissolved oxygen by air-to-water oxygen transfer.

Calculating Oxygen Transfer Rates

Standard tests of aerators are conducted according to guidelines of the American Public Health Association. These tests use clean tap water held at 20°C (68°F) with an initial dissolved-oxygen concentration of 0 ppm. Test results are expressed in kilograms of oxygen transferred to the water per kilowatt hour. In English units, 1 kilogram per kilowatt hour equals 1.64 lb. per horsepower hour. In practical applications, an aerator does not transfer oxygen at the rate determined in standard tests because pond waters seldom have the same concentration of dissolved oxygen at saturation or the same oxygen-transfer coefficient (K_La) that tap water has. Further, pond waters are rarely precisely 20°C (68°F) and rarely contain 0 ppm dissolved oxygen. Table 2 shows factors to calculate oxygen-transfer rates for pond conditions.

Table 2.--Correction factors to calculate oxygen transfer rates for pond conditions

Dissolved Oxygen mg/liter (ppm)	Water Temperature °C					
	10	15	20	25	30	35
0	0.71	0.71	0.72	0.74	0.76	0.79
1	0.64	0.64	0.64	0.65	0.66	0.67
2	0.57	0.56	0.55	0.55	0.55	0.55
3	0.51	0.49	0.47	0.45	0.44	0.43
4	0.44	0.41	0.38	0.36	0.33	0.30
5	0.37	0.34	0.30	0.26	0.22	0.18
6	0.31	0.26	0.21	0.17	0.12	0.06
7	0.24	0.19	0.13	0.07	0.01	0.0
8	0.17	0.11	0.04	0.0		
9	0.11	0.04	0.0			
10	0.04	0.0				
11	0.0					

The fish culturist can use these factors to accurately calculate oxygen-transfer rates for aerators in specific conditions. For example, if an aerator rated to supply 2 kg O_2/kwatt-hr is operating in a pond with an oxygen concentration of 2 ppm and a water temperature of 30°C (86°F), the rating would be multiplied by 0.55 (table 2). The aerator could be expected to transfer 0.55 x 2 kg O_2/kwatt-hr or 1.1 kg O_2/kwatt-hr (1.8 lb. O_2 per horsepower-hr).

If a fish culturist were using this aerator in a production pond 8 ha (20 acres) in size with an average depth of 1.5 m (5 ft) and a water temperature of 30°C (86°F) and using a tractor delivering 50 horsepower to operate the aerator, he could calculate how long it would take to raise the O_2 level from 2 ppm to 5 ppm. Each hour the tractor is operated should transfer 40 kg (90 lbs.) of O_2 to the pond (50 x 1.8). This pond has a total volume of 121,410 m^3. Since 1 gram per cubic meter is equivalent to 1 ppm, the amount of oxygen needed to raise the O_2 level 1 ppm is 120 kg (267 lbs.). The aerator described above would have to operate approximately 3 hours for each 1 ppm increase in O_2 content (120 ÷ 40). In the above example, the time required to raise the O_2 level from 2 ppm to 5 ppm would be about 9 hours.

An effective emergency aeration system should be capable of raising a dissolved oxygen concentration of 0 to 2 ppm by at least 2 ppm in 15 to 20 percent of a pond's area within 4 hours. In the above example, 20 percent of the area is 24,282 m^3. For this volume, 24 kg (53 lbs.) of O_2 would be required for each 1 ppm increase in concentration of dissolved oxygen. The aerator described above would raise the content of dissolved oxygen from 2 ppm to 4 ppm in about 1 hour and 10 minutes [2 x (24 ÷ 40)].

Types of Aerators

Gravity Aerators.--Gravity aerators use the energy released when water falls or splashes. Waterfalls are very effective natural aerators. Water passing over a fall breaks up into droplets, increasing the surface area. Dams, channel-drop structures, pipe overfalls, fish ladders, and fish raceways constructed in series are examples of man-made gravity aerators, regardless of whether or not they are designed for that purpose. Gravity aerators are widely used in aquaculture systems where large volumes of water and differences in elevation are available, either naturally or by pumping.

In cultural systems in which the water level is controlled by weirs, water spilling over a weir is a common aerator (fig. 6). The water that spills over a weir can be further aerated if it splashes across a splashboard or is allowed to cascade down either a lattice or perforated inclined plane. Weir-type splash aerators constructed in fish raceways are in common use in trout culture and other cool-water production facilities where large volumes of flowing water are used. The cooler waters contain a higher concentration of dissolved oxygen when fully saturated than do warmer waters typical in the southern states.

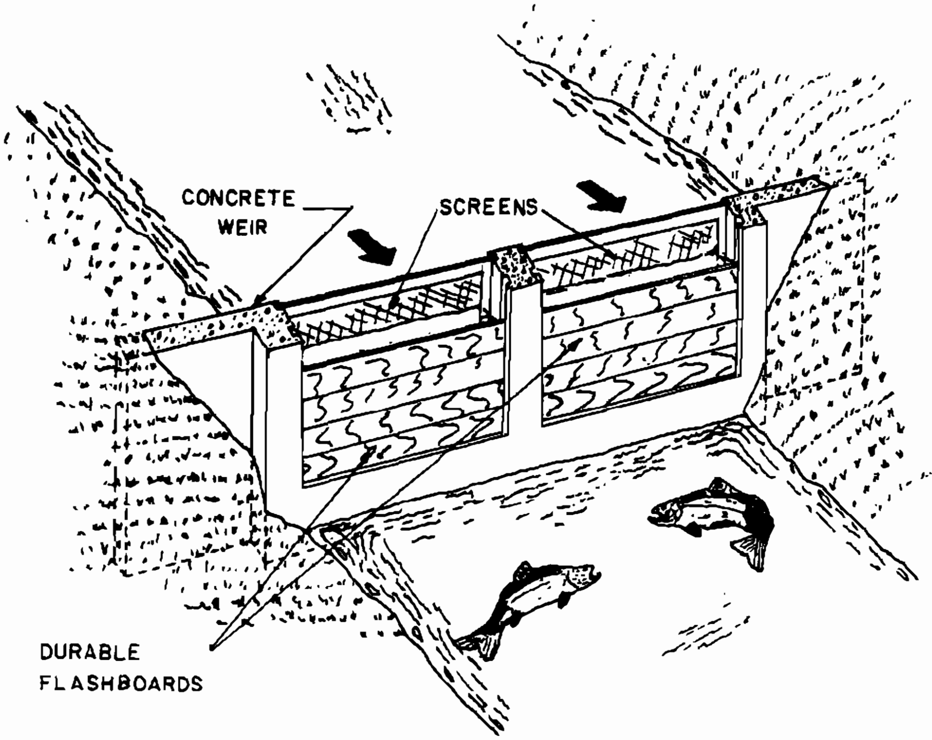

Figure 6.--Weir-type splash aerator.

When differences in elevation occur either naturally, by impoundment or by pumping, the water can be aerated by passing it through a pipe to a lower level, then up through a riser with perforated aprons.

Diffuser Aerators.--Diffuser-type aerators inject air or oxygen into a body of water in the form of a bubble stream well below the surface (fig. 7). The air or oxygen is made available either from a

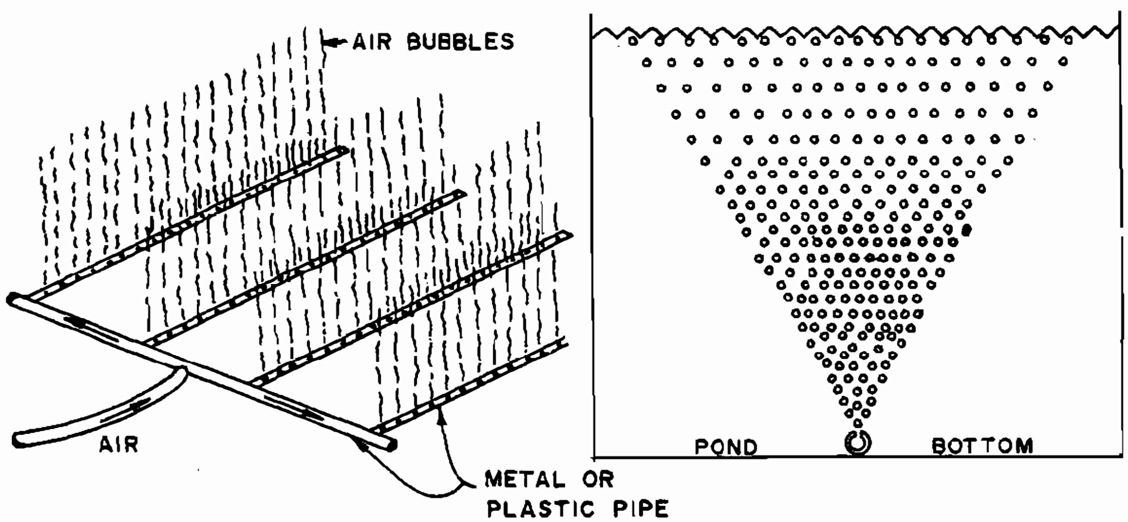

Figure 7.--Diffuser-type aerator or sparger.

pressurized source (blower) or from an aspirator system where a vacuum is created and air is drawn into the system. Both systems require pumps.

Transfer of oxygen to the water across the gas-liquid interface is a relatively slow diffusion process. For that reason, this type of aerator is most effective in deeper ponds where bubbles are in the water for longer periods. Diffuser-type aerators have little effect in emergency situations.

Portable Emergency Aerators.--The following discussion covers the principal types of portable emergency aerators used in commercial aquaculture. This does not constitute an endorsement of any equipment nor does the omission of certain types imply unworthiness.

- Surface Aerators--These are devices that break up or agitate the water surface. They include sprayers 1/, rotary propellers that create a hydraulic jump or wave across the water surface, and rotary paddles (paddle wheels) partly submerged and rotated at high speed.

Typically, a paddle-wheel aerator consists of blades (paddles) mounted on the axles of a truck differential and rotated by a drive shaft connected to the power take-off of a farm tractor (fig. 8). The speed of rotation is controlled by the tractor throttle setting. These aerators provide a large amount of oxygenation per unit, are relatively inexpensive (apart from the tractor), and are durable, mobile, and easy to operate.

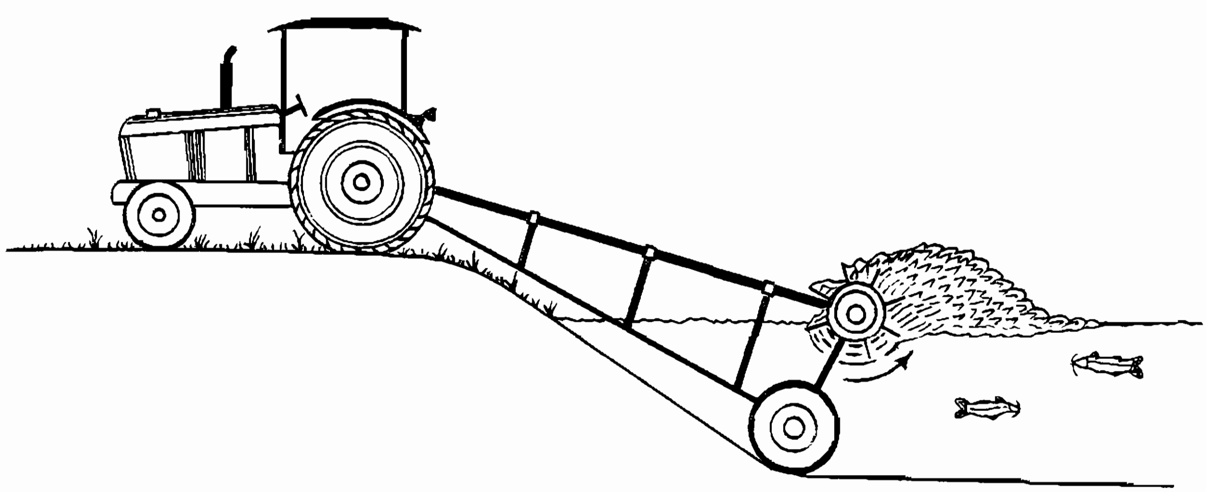

Figure 8.--Tractor-powered paddle-wheel aerator.

1/ If also used to apply chemicals to cropland, sprayers must be cleaned thoroughly before they are used as aerators.

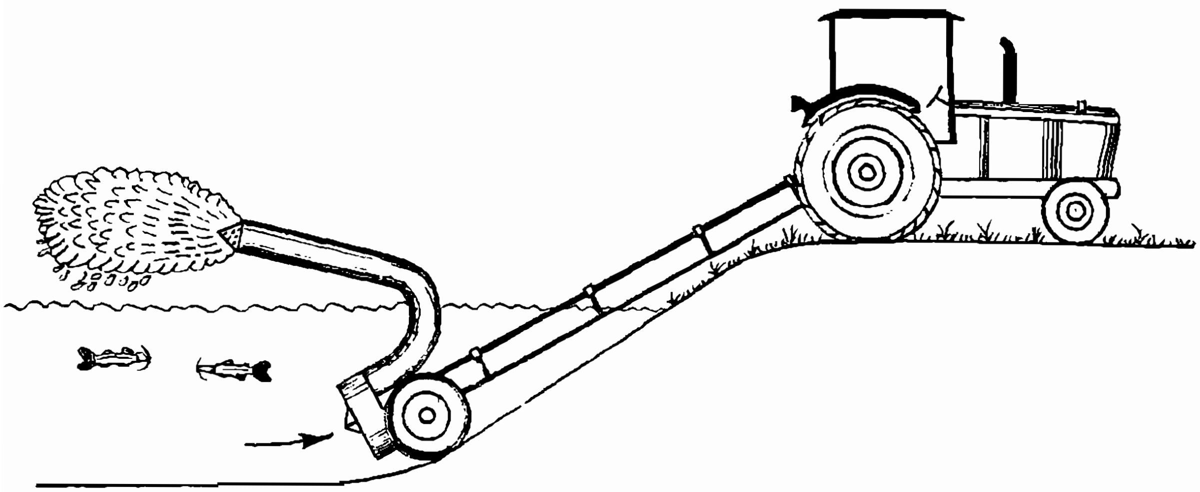

Figure 9.--Tractor-powered Crisafulli pump aerator.

Crisafulli pumps are used to transfer water from one pond to another one nearby or to lift subsurface water from a pond and spray it across the surface of the same pond (fig. 9). They are generally powered by a farm tractor and have advantages similar to paddle-wheel aerators.

In larger ponds, sprayer-type circular surface aerators operated by electricity (fig. 10) are not as effective as are paddle-wheels and Crisafulli pumps. But in small ponds, holding tanks, and circular raceways, they are effective.

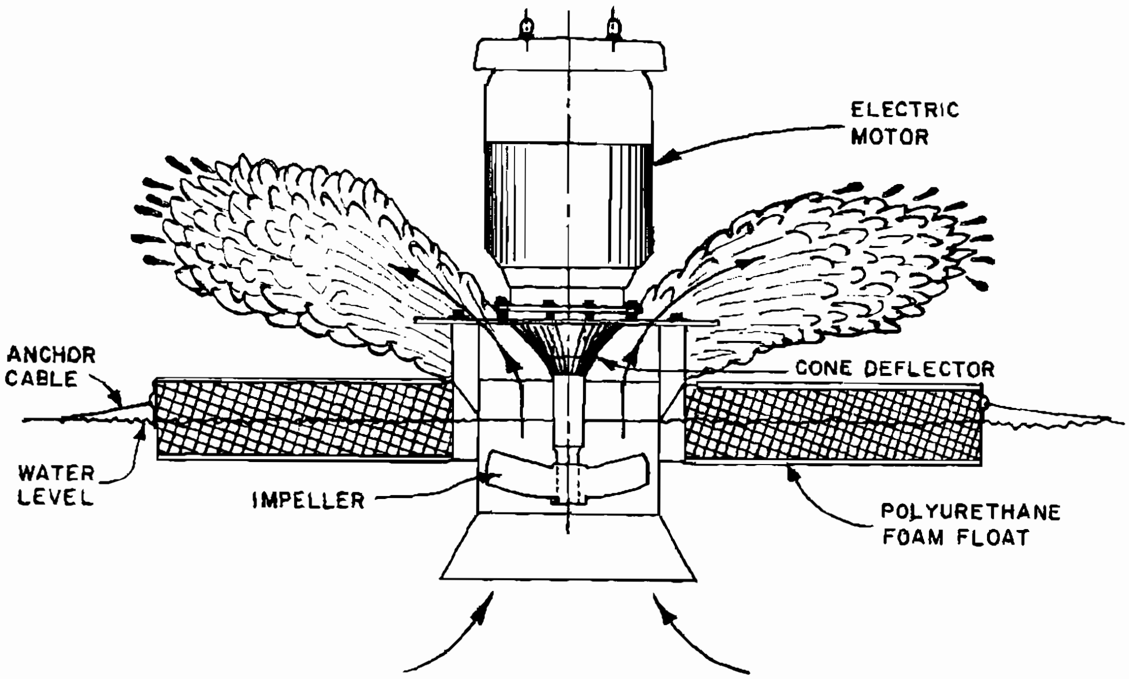

Figure 10.--Sprayer-type circular aerator.

o <u>Turbine Aerators</u>.-- A turbine aerator is a propeller submerged in the pond. As the propeller rotates, it circulates the water, causing greater aeration to occur at the surface.

An aeration system in limited but growing use is a modified Garton ventilating fan destratifier (fig. 11). This device is a form of turbine aerator. It is most effective in deeper ponds where a distinct thermocline layer exists in a natural condition. The modified fan destratifier consists of a frame that is about 1.3 m x 1.3 m (52 inches square) and 1.2 m (48 in.) deep, has expanded flotation around the top and is anchored in the pond. A 1.0-to 1.5-hp electric motor is mounted on top of the frame. It is connected through a right-angle reduction gear box to a vertical shaft on which a 1.2 m (48-in.) diameter fan blade is attached. To prevent damage to the blade, the frame is surrounded by wire mesh.

To be most effective, the destratifier must be in operation before stratification begins. In the southern states, destratifiers are usually operated from late April or early May until about October.

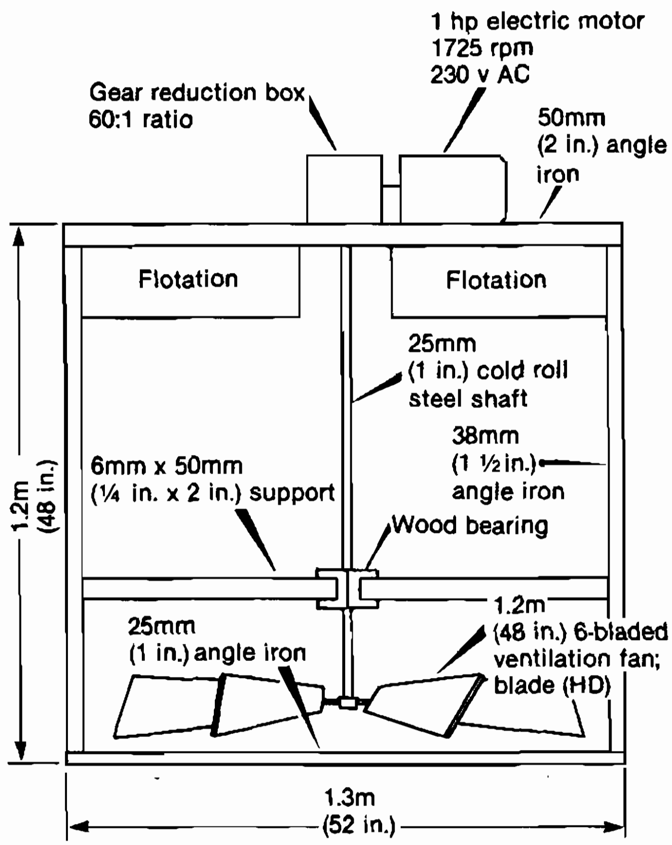

Figure 11.--Modified Garton ventilating fan destratifier.

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