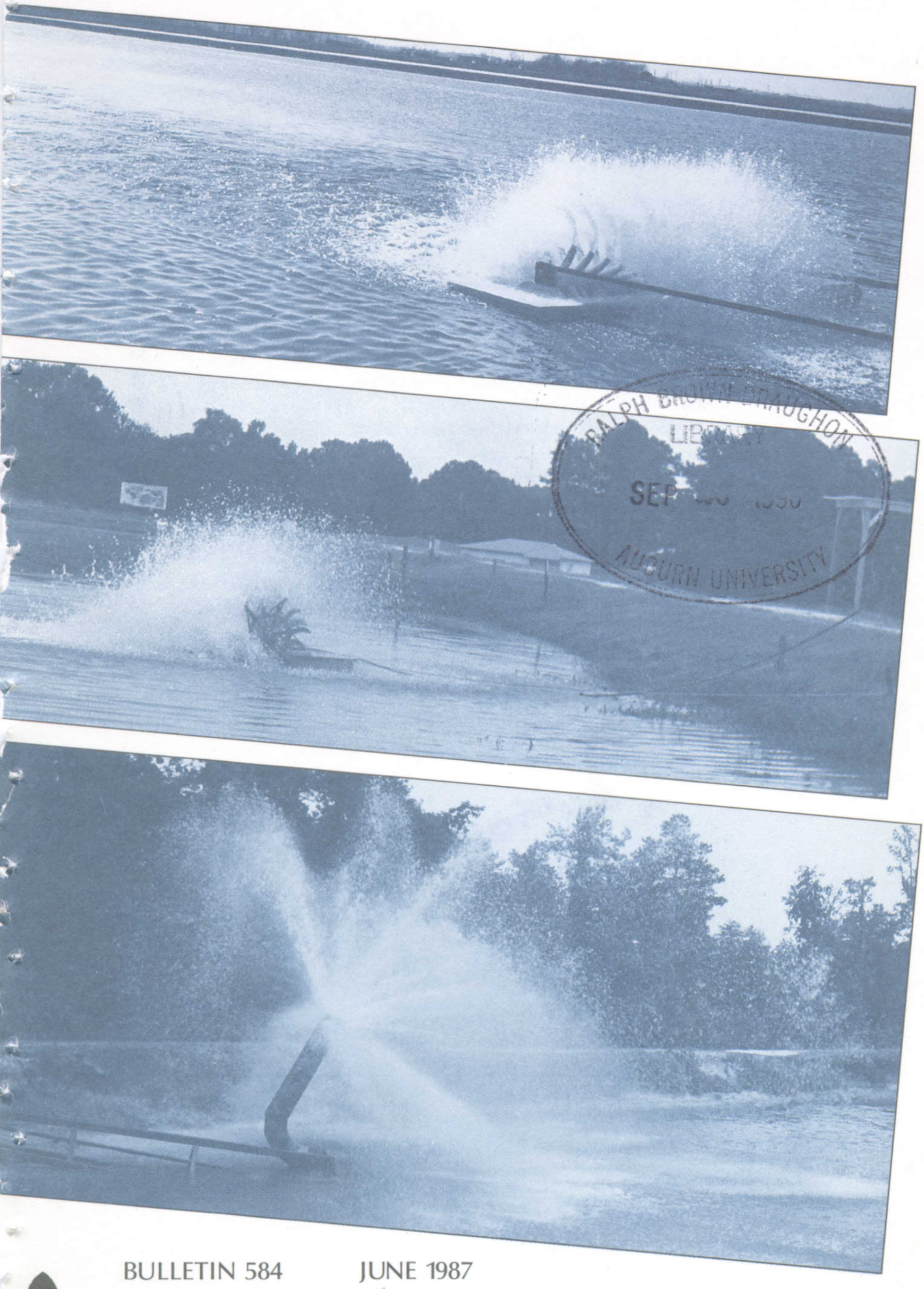
EVALUATION OF AERATORS FOR CHANNEL CATFISH FARMING



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Evaluation of Aerators For Channel Catfish Farming

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INTRODUCTION

CHANNEL catfish farming is a profitable endeavor which is expanding rapidly in the United States. The acreage devoted to channel catfish ponds is increasing at a rate of about 10 percent per year, and production of fish per acre also is rising.

A major problem in catfish farming is the low concentrations of dissolved oxygen (DO) which result from high fish stocking and feeding rates necessary to assure profit (*4,19*). For years, catfish farmers have relied on large, emergency aerators powered by power take offs (PTOs) of farm tractors to prevent fish stress and mortality at times when DO concentrations were low (*4,8,19*). This practice is expensive because a tractor must be available to power each emergency aerator, and many aerators are necessary for large catfish farms. To reduce dependence on tractor-powered aerators, some fish farmers have begun to invest heavily in smaller, floating, electric ones. When used at 1 to 3 horsepower (hp) per acre in research ponds, floating, electric aerators permit greater fish production, and they prevent most crises with low DO (*10,12,14*). In practice, fish farmers usually aerate at only 0.5 to 1.0 horsepower per acre, but even these rates result in improved fish production at these aeration rates. The overall cost of aeration is less with electric aerators than with tractor-powered aerators. However, tractor-powered aerators probably will not be replaced entirely, because they can be used when DO crises are too severe to be managed with smaller, electric aerators. Also, some catfish ponds do not have electrical services. Most aerators used in catfish farming have been designed and fabricated by fish farmers or

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local machine shops. Tractor-powered aerators have been subjected to few performance tests (*2,7,9,13*), but even less information is available on the performance of electric aerators (*6*).

Electric aerators are used widely in wastewater treatment. These aerators have been subjected to years of research, development, and testing, and performance information is available from their manufacturers. Aerators for wastewater treatment usually are too expensive for application in catfish farming, but a few pollution equipment companies have sold aerators to catfish farmers.

During the past 3 years, performance tests on a number of tractor-powered and electric aerators which are used in catfish farming have been performed at the Alabama Agricultural Experiment Station. A description of these tests and results obtained are presented in this report, following an explanation of the principles of aeration.

Principles of Aeration

The air contains 20.95 percent oxygen. At standard barometric pressure (29.92 inches of mercury), the pressure of oxygen in air is 6.27 inches of mercury (29.92 × 0.2095). This, of course, varies with barometric pressure. The pressure of oxygen in the air drives oxygen into water until the pressure of oxygen in water is equal to the pressure of oxygen in the air. When the pressure of oxygen in water and air are equal, net movement of oxygen molecules from air to water ceases. The water is said to be at equilibrium, or at saturation, with DO when the oxygen pressure (sometimes called oxygen tension) equals that of the air. The concentration of DO in water at saturation varies with temperature and barometric pressure. As water temperature increases, the DO concentration at saturation decreases, table 1. DO concentrations in table 1 are given in parts per million (p.p.m.); 1 p.p.m. = 1 milligram per liter (mg/1). At a given temperature, the DO concentration at saturation increases in proportion to increasing barometric pressure.

Plants growing in water produce oxygen by photosynthesis, and during daylight hours plants in fish ponds often produce oxygen so fast that DO concentrations in the water rise above saturation. Water containing more DO than expected for the water temperature and barometric pressure is said to be supersaturated with DO. When water is supersaturated with DO, the pressure of oxygen in water is greater than the pressure of oxygen in air.

Water also may contain less DO than expected at saturation. At night respiration by fish, plants, and other pond organisms causes DO levels to decline. Thus, during warm months nighttime DO con-

TABLE 1. DISSOLVED OXYGEN (DO) CONCENTRATIONS AT SATURATION FOR DIFFERENT TEMPERATURES (1)

Temperature, degree C[1]	DO	Temperature, degree C[1]	DO
	p.p.m.		*p.p.m.*
0 (32)	14.60	18 (64)	9.45
1 (34)	14.19	19 (66)	9.26
2 (36)	13.81	20 (68)	9.07
3 (37)	13.44	21 (70)	8.90
4 (39)	13.09	22 (72)	8.72
5 (41)	12.75	23 (73)	8.56
6 (43)	12.43	24 (75)	8.40
7 (44)	12.12	25 (77)	8.24
8 (46)	11.83	26 (78)	8.09
9 (48)	11.55	27 (80)	7.95
10 (50)	11.27	28 (82)	7.81
11 (52)	11.01	29 (84)	7.67
12 (53)	10.76	30 (86)	7.54
13 (55)	10.52	31 (88)	7.41
14 (57)	10.29	32 (90)	7.28
15 (59)	10.07	33 (92)	7.16
16 (61)	9.85	34 (93)	7.05
17 (62)	9.65	35 (95)	6.93

[1] Numbers in parenthesis are degrees F.

centrations in ponds often are below saturation (the pressure of oxygen in water is less than the pressure of oxygen in the air).

When water is below saturation with DO, there is a net movement of oxygen molecules from air to water. At saturation with DO, the number of oxygen molecules leaving the water equals the number entering (no net movement). There is net movement of oxygen molecules from water to air when water is supersaturated with DO. The greater the difference between the pressure of oxygen in water and air, the larger the movement of oxygen molecules from air to water or vice versa.

The concentration of DO at saturation for a particular water temperature and atmospheric pressure may be calculated as follows:

$$C_s = C_{tab} \times \frac{BP}{29.92}$$

where C_s = DO concentration at saturation (p.p.m.);
C_{tab} = DO concentration at the existing temperature and standard barometric pressure, table 1 (p.p.m.);
BP = barometric pressure (inches of mercury);
29.92 = standard atmospheric pressure at sea level (inches of mercury).

For rigorous calculations, the vapor pressure of water must be subtracted from both the numerator and denominator of the above equation (*11*). However, for practical purposes, this adjustment may be ignored (*1*).

The percentage saturation of water with DO may be estimated as:

$$S = \frac{C_m}{C_s} \times 100$$

where S = percentage saturation with DO;
C_m = measured concentration of DO in water (p.p.m.).

The pressure or tension of DO in water can be estimated as:

$$Po_2 = \frac{C_m}{C_s} \times 0.2095 \times 29.92$$

where Po_2 = DO pressure in water (inches of mercury).

The DO pressure in water can be thought of as the equivalent pressure of oxygen in air necessary to hold the observed concentration of DO in the water.

The oxygen deficit is the difference between the measured DO concentration and the DO concentration at saturation. That is:

$$OD = C_s - C_m$$

where OD = oxygen deficit (mg/1).

The value for OD will be positive when the DO concentration in water is below saturation and negative when the DO concentration in water is greater than saturation. The value of OD may be expressed as a pressure difference if C_s and C_m are in pressure rather than concentration. Oxygen moves from air to water and vice-versa by diffusion, and the rate of oxygen diffusion depends upon the oxygen deficit. The oxygen deficit is the driving force causing oxygen to enter or exit the water surface.

Obviously, at a given oxygen deficit, the amount of oxygen that can enter a given volume of water in a specified time interval depends upon the area of water surface relative to water volume. The amount of oxygen entering increases with greater surface area. Oxygen from the air readily enters the surface film, and the DO concentration in the surface film quickly reaches saturation. The movement of oxygen from the surface film throughout the entire volume of water is much slower than the initial entry of oxygen into the surface film. Thus, in still water, the surface film quickly saturates with DO, and the rate of diffusion of oxygen into water becomes slow, because no more oxygen can diffuse from air into the surface film until some of the oxygen in the surface film diffuses into the greater volume of water.

The importance of mixing of water on oxygen transfer between air and water should be apparent. Mixing makes the surface rough and thereby increases surface area. Mixing also causes mass transfer (convection) of water and DO from the surface to other places within the water body. Mixing of pond water by wind favors diffusion of oxygen, so more oxygen diffuses into or out of pond water on a windy day than on a calm day.

The rate of change in the oxygen deficit (or the rate of change in mass oxygen transfer) with time depends upon the oxygen-transfer coefficient, and the oxygen-transfer coefficient depends upon turbulence of water (degree of mixing), area of water surface, and water volume. Surface area varies with turbulence, and neither variable can be estimated accurately. Nevertheless, it is possible to calculate the overall oxygen-transfer coefficient with the following equation:

$$K_La = \frac{\ln OD_1 - \ln OD_2}{(t_1 - t_2)/60}$$

where K_La = overall oxygen-transfer coefficient (hour^{-1});
ln = natural logarithm;
OD_1 = oxygen deficit at t_1 (p.p.m.);
OD_2 = oxygen deficit at t_2 (p.p.m.);
t_1 = time 1 (minute);
t_2 = time 2 (minute).

Aerators influence the rate of oxygen transfer from air to water by increasing turbulence and surface area of water in contact with air. Aerators are of two basic types: splashers and bubblers. An example of a splasher aerator is a paddle wheel aerator. It splashes water into the air to affect aeration. Splashing action also causes turbulence in the body of water being aerated. Bubbler aerators rely upon release of air bubbles near the bottom of a water body to affect aeration. A large surface area is created between air bubbles and surrounding water. Rising bubbles also create turbulence within a body of water.

Aerators are tested to determine the rate at which they transfer oxygen to water. Tests are conducted in a tank of known volume. Water in the test tank is deoxygenated, and the aerator is operated to effect re-aeration. Concentrations of DO are measured at timed intervals during re-aeration. These data are used, as described later, to estimate the amount and efficiency of oxygen transfer under standard conditions (0 p.p.m. DO, 68°F, and clean tap water).

The standard oxygen transfer rate (SOTR) is defined as the pounds of oxygen that an aerator will transfer in 1 hour. The standard aeration efficiency (SAE) is obtained by dividing SOTR by power input to give the pounds of oxygen transferred per horsepower-hour. SOTR and SAE values are for aerators operating in clean water at 68°F and containing 0 p.p.m. DO. These conditions seldom exist in fish ponds.

The rate that an aerator transfers oxygen to water decreases with increasing DO concentration and to a lesser extent with increasing temperature. Clean water often aerates faster than water from fish ponds. The α value is a measure of the difference in the aeration rate of pond water and clean water when both are at the same temperature:

$$\alpha = \frac{\text{Oxygen-transfer coefficient for pond water}}{\text{Oxygen-transfer coefficient for clean water}}$$

The actual oxygen transfer rate for an aerator operating in a fish pond can be estimated with the following equations:

$$\text{OTR} = \text{SOTR} \times \frac{C_s - C_p}{9.07} \times 1.024^{T-20} \times \alpha$$

where OTR = Oxygen transfer rate in pond water (pounds O_2/hour);
C_p = DO concentration in pond water (p.p.m.);
9.07 = C_s at 68°F and 29.92 inches of mercury (p.p.m.);
T = Water temperature (°C).

If one is interested in aerator performance in brackish or salt water, the C_s value in the preceding equation must be adjusted for salinity. Also, the value for C_s at 68°F and 29.92 inches of mercury must be determined for the existing salinity and this value used in place of 9.07 in the preceding equation. Strickland and Parsons (*17*) provided a nomograph for estimating DO concentration at saturation in waters of different salinities.

Aeration efficiency (AE) for pond conditions can be estimated by using SAE instead of SOTR in the preceding equation.

Estimation of OTR and AE is seldom attempted for fish ponds. The primary value of SOTR and SAE in fish farming is for comparing aerators. An aerator with a high SOTR value will transfer more oxygen than an aerator with a low SOTR value when aerators are operating under similar conditions. Likewise, for comparable operating conditions, an aerator with a high SAE will transfer oxygen more efficiently than an aerator with a low SAE. SOTR and SAE values are comparable to standard gas mileage ratings which are provided by automobile manufacturers. Gas mileage ratings permit prospective automobile buyers to compare cars, but buyers realize that under actual driving conditions gas mileage will be less than the standard gas mileage rating.

Water Circulation

Circulation of pond water by aerators is beneficial for several reasons: (1) oxygenated water moves across the pond and fish can more readily find zones with adequate DO concentrations; (2) without constant movement of well oxygenated water away from the aerator, aeration will increase DO concentrations in the vicinity of the aerator and greatly reduce oxygen-transfer efficiency; and (3) mixing of pond water by aerators reduces vertical stratification of temperature and chemical substances.

Boyd and Martinson (6) developed two techniques for estimating the water circulating abilities of aerators. One procedure involved pouring a brightly colored dye in the water around an aerator and determining how long it took an aerator to spread the dye over the entire pond surface. In the other method, a concentrated solution of salt (NaCl) was poured into the water around the aerator. Specific conductance values were measured at several sites and depths in the pond at timed intervals until specific conductance was uniform throughout the water volume. The time necessary to effect uniform specific conductance was taken as the time required to completely mix the pond water. The mixing rate was calculated as follows:

$$\mathrm{MR} = \frac{(\mathrm{A})(\mathrm{D})}{(\mathrm{P})(\mathrm{T})}$$

where MR = mixing rate (acre-foot/horsepower-hour)
A = pond area (acres)
D = average depth of pond (feet)
P = aerator size (horsepower)
T = time to homogenously mix salt throughout pond volume (hour)

Boyd and Martinson (6) and Petrille and Boyd (*13*) determined mixing rates for several different types of tractor-powered and electrically powered aerators. In general, mixing rates increased with increasing SOTR values for tractor-powered aerators and with increasing SAE for electric aerators. This is logical because vigorous splashing or stirring of water is necessary for efficient oxygen transfer with surface aerators, and vigorous splashing will induce strong water circulation. Among tractor-powered aerators, the Airmaster (described later) and a paddle wheel aerator were most effective in mixing pond water (*13*). Electric propeller aspirator pump aerators

(Air-0_2 aerators) were more efficient in mixing pond water than vertical pump aerators and diffused-air aerators. Mixing tests were not conducted with electric paddle wheel aerators.

If an aerator is efficient in oxygenating water, it will usually induce adequate water circulation. Excessive water circulation should be avoided, because turbidity from suspended soil particles may result. Therefore, in the present study, aerators were tested only for their abilities to transfer oxygen to water.

Test Methods

Aerator tests were conducted in small ponds (0.1 or 0.25 acre) or in concrete tanks (160, 784, or 1,400 or 5,400 square feet). Water depth averaged 3 feet in ponds. Water was of uniform depth in tanks; depths ranged from 2.5 to 3.5 feet in different tests. Ponds and tanks were rectangular in shape with lengths approximately twice widths. Tractor-powered pump sprayer aerators and squirrel cage aerators were tested in ponds; other aerators were tested in tanks.

Aerator performance tests followed accepted guidelines (1,3,5,18). Water in ponds or tanks was deoxygenated by applying sodium sulfite and cobalt chloride. Sodium sulfite removes oxygen according to the following reaction:

$$Na_2S0_3 + 1/2\ 0_2 \rightarrow Na_2S0_4.$$

Cobalt chloride catalyzes the reaction between sodium sulfite and oxygen. To remove 1 p.p.m. of DO requires 8 p.p.m. of sodium sulfite. Cobalt chloride was added to provide 0.075 p.p.m. of cobalt. The two chemicals were dissolved in containers of water (5 to 35 gallons) and splashed over water surfaces of tanks or ponds. Chemicals were mixed with waters of test basins by running aerators.

A polarographic DO meter (Yellow Springs Instrument Co., Model 57) was used to measure DO concentrations at timed intervals while DO rose from near 0 percent to 80 or 90 percent of saturation. Concentrations of DO were measured at three different places in tanks and at five different places in ponds. Time intervals ranged from 15 seconds to 4 minutes for different aerators; measurements were made over at least 10 time intervals in each test.

Concentration of DO at saturation was calculated by adjusting the appropriate saturation concentration from table 1 for barometric pressure. Deficits of DO were estimated for each time interval by subtracting measured DO concentrations from concentration of DO at saturation. Natural logarithms of oxygen deficits were plotted versus time of aeration. The line of best fit was drawn by visual inspection of plotted points. The oxygen transfer coefficient was calculated with the following equation:

$$(K_La)_T = \frac{\ln OD_{10} - \ln OD_{70}}{t_{70} - t_{10}}$$

where $(K_La)_T$ = overall oxygen-transfer coefficient for the existing water temperature (hour^{-1});
OD_{10} = oxygen deficit at 10 percent of saturation (p.p.m.);
OD_{70} = oxygen deficit at 70 percent of saturation (p.p.m.):
t_{10} = time when DO reaches 10 percent of saturation (hour);
t_{70} = time when DO reaches 70 percent of saturation (hour);

Data for solution of the above equation were obtained from the graph of DO deficit versus time of aeration. The $(K_La)_T$ value was adjusted for 20°C (68°F) as follows:

$$(K_La)_{20} = K_La_T \div 1.024^{T-20}$$

where $(K_La)_{20}$ = overall oxygen-transfer coefficient at 20°C (hour^{-1});
T = water temperature for test (°C).

Aerator tests were conducted in tanks filled with pond water. In order to adjust $(K_La)_{20}$ values to clean water conditions, values were determined. Water samples from test basins were brought to the laboratory and bench-scale aeration tests were conducted by aerating water in 4-liter beakers with an air pump and air stone (*16*). Comparison tests were conducted with tap water, and values were computed:

$$\alpha = \frac{(K_La)_{20} \text{ pond water}}{(K_La)_{20} \text{ tap water}}$$

Next, the adjusted overall oxygen-transfer coefficient $\left[(K_La)'_{20}\right]$ was obtained:

$$(K_La)'_{20} = (K_La)'_{20} \div \alpha$$

The standard oxygen-transfer rate (SOTR) in pounds oxygen per hour was estimated as follows:

$$\text{SOTR} = (K_La)'_{20} \times 9.07 \times V \times 10^{-3} \times 2.205$$

where 9.07 = DO concentration at 20°C (68°F) and standard atmospheric pressure (g/m^3) (1 g/m^3 = 1 p.p.m.);
V = tank volume (m3);
10^{-3} = factor for converting grams to kilograms;
2.205 = factor for converting kilograms to pounds.

Standard aeration efficiency (SAE) in pounds of oxygen per horsepower-hour was obtained by dividing SOTR by horsepower applied to the aerator shaft.

At least three oxygen-transfer trials were conducted for each aerator. Aeration tanks or ponds were drained after a maximum of eight oxygen-transfer trials and refilled.

In tests with electric aerators, current (amperes) was measured to determine if the aerator was drawing the rated current. If it was, the horsepower applied to the aerator shaft was assumed to be the rated motor output horsepower, or if a gear reducer was used, the horsepower applied to the aerator shaft was estimated as motor output horsepower times the gear reducer efficiency. Voltage readings were obtained with a voltmeter, and power measurements were made with a TIF Model 2000A clamp-on digital watt meter. In cases where the aerator was drawing less than the rated current, the horsepower supplied to the aerator shaft was estimated for three-phase motors by the equation:

$$\text{horsepower} = \frac{\sqrt{3} \times I \times E \times PF \times Eff}{746}$$

where I = current (amperes);
E = voltage (volts);
PF = power factor;
Eff = combined motor and gear reducer efficiency.

For single-phase motors, the $\sqrt{3}$ term was omitted from the above equation. No attempt was made to determine the power applied to the shafts of tractor-powered aerators.

A Biddle speed indicator determined aerator shaft speeds.

TRACTOR-POWERED AERATORS

Tractor-powered aerators included pump sprayers, squirrel cages, and paddle wheels. These portable aerators were mounted on trailers and powered by PTOs of large farm tractors (50 horsepower or more). In practice, the use of tractor-powered aerators is restricted to emergency aeration during periods when DO concentrations are dangerously low.

Because the horsepower applied to the aerator shaft was not measured for tractor-powered aerators, SAE values were not calculated.

Pump Sprayer Aerators

Crisafulli—The pump, which is manufactured by Crisafulli Pump Co., Glendive, Montana, had a 16-inch-diameter by 8.88-inch-wide impeller and a 12-inch-diameter discharge, figure 1. The sprayer was a 12-inch-diameter pipe which extended 5 feet above the centerline of the pump outlet. The end of the pipe was capped with a cone which was perforated with 127, 0.5-inch diameter holes. Six large slots (0.5-inch x 3-inch) and six small slots (0.5-inch x 1.5-inch) were cut into the pipe just below the cap on the side of the pipe facing the pond. The pump was operated with a 65-horsepower tractor. The tractor PTO turned at 540 r.p.m.; the pump shaft rotated at the same speed.

FIG. 1. Crisafulli tractor-powered pump sprayer aerator.

SOTR for the Crisafulli pump sprayer aerator was 17.3 pounds of oxygen per hour, table 2.

Spree - This pump sprayer was constructed by Thed Spree, Boligee, Alabama. It was similar in appearance, figure 2, to the Crisafulli pump sprayer. The pump has a 16-inch-diameter by 6-inch-wide impeller and an 18-inch-diameter discharge. The discharge outlet was fitted with an 18-inch-diameter pipe which extended 5 feet above the centerline of the pump outlet. The pipe was capped with a flat plate. The side of the pipe facing the pond was perforated with 14 slots (2-inch x 4-inch). The pump shaft was rotated at 540 r.p.m. by a 65-horsepower tractor.

A SOTR of 26.5 pounds of oxygen per hour was achieved for the Spree pump sprayer aerator, table 2.

Airmaster - This aerator is manufactured by Mastersystems, Inc., Greenwood, Mississippi. The pump has an 18-inch-diameter by 8-inch-wide double-intake impeller. The pump casing was connected to a 10-inch-diameter by 10-foot-long manifold which contained a 5.5-inch-diameter hole in each end and 30 discharge ports in the top. Each port is constructed by cutting a 0.125-inch slit for 300° around a radius of 2 inches. Water sprayed vertically through ports and laterally through holes at the end of the manifold, figure 3. The pump was powered by an 80-horsepower tractor which turned the pump shaft at 1,000 r.p.m.

The Airmaster pump sprayer aerator had an SOTR of 46.9 pounds of oxygen per hour, table 2.

Big John Aerator - Southern Machine Welding, Inc., Quinton,

TABLE 2. STANDARD OXYGEN TRANSFER RATES (SOTR) FOR TRACTOR-POWERED EMERGENCY AERATORS ARE DESCRIBED IN THE TEST

Aerator[1]	Tractor size	Aerator shaft speed	SOTR[2]
	Horsepower	*r.p.m.*	*Lb. O_2/hr.*
Waterblower(PS)	200	1,000	162.8 ± 8.9
House Manufacturing(PW)	65	540	65.7 ± 3.2
Auburn Univ., concave paddles(PW)	65	540	58.0 ± 3.5
Airmaster(PS)	80	1,000	46.9 ± 2.4
Auburn Univ., flat paddles(PW)	65	540	43.3 ± 2.6
McCray(SC)	65	400	37.3 ± 4.2
Spree(PS)	65	540	26.5 ± 0.9
Big John(PS)			
45° elbow sprayer	50	540	20.2 ± 3.1
Tee sprayer	50	540	19.7 ± 2.9
McClendon(SC)	65	400	17.3 ± 1.3
Crisafulli(PS)	65	540	17.3 ± 1.1

[1] PS = pump sprayer aerator; PW = paddle wheel aerator; SC = squirrel cage aerator.
[2] Mean ± 1 standard error.

FIG. 2. Spree tractor-powered pump sprayer aerator.

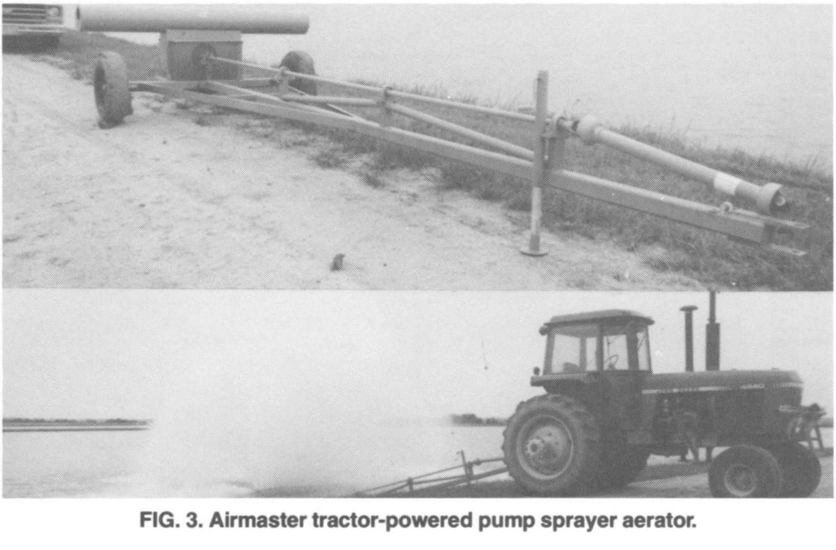

FIG. 3. Airmaster tractor-powered pump sprayer aerator.

Alabama, manufactured this aerator, figure 4. The pump had an 18-inch-diameter by 5-inch-wide double intake impeller with an 8-inch-diameter discharge. The sprayer was fabricated of 8-inch-diameter PVC pipe. Two types of sprayers were tested. One consisted of a pipe fitted at its discharge end with a tee. The other was fitted at its discharge end with a 45° elbow. The aerator was powered by a 50-horsepower tractor; the pump shaft was rotated at 540 r.p.m.

The 45° elbow sprayer had a SOTR of 20.2 pounds of oxygen per hour, while the tee sprayer had a SOTR of 19.7 pounds of oxygen per hour, table 2.

Water Blower - This aerator was built by Richard Koehn, Walnut Grove, Florida. The pump had an 18-inch-diameter by 4-inch-wide double-intake impeller. The sprayer was a continuation of the pump casing which gradually reduced in size to 6.5-inch-diameter at its discharge end, figure 5. The angle of the sprayer with the water surface was adjustable. In tests, the discharge end of the sprayer was 1

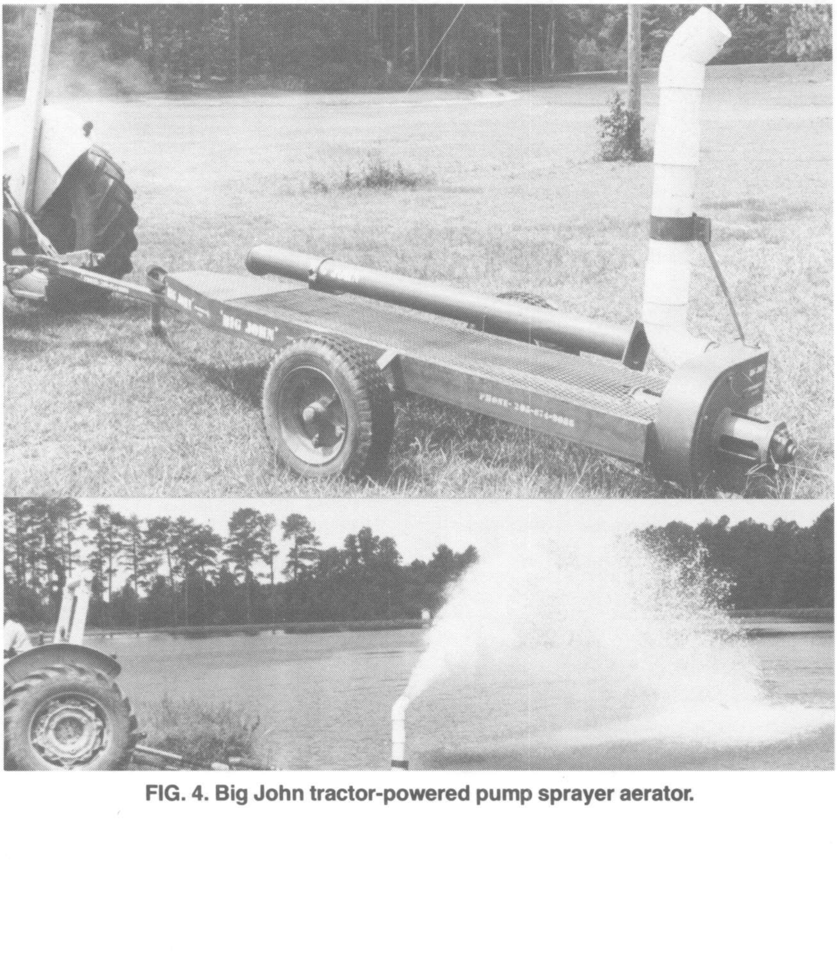

FIG. 4. Big John tractor-powered pump sprayer aerator.

FIG. 5. Waterblower tractor-powered pump sprayer aerator.

foot above and parallel to the pond surface. The aerator was powered by a large tractor which was turbocharged to approximately 200 horsepower. The pump shaft was rotated at 1,000 r.p.m.

The Water Blower had a very high SOTR of 162.8 pounds of oxygen per hour, table 2.

Squirrel Cage Aerators

McLendon - This aerator, figure 6, was built by Wayne McLendon, Opelika, Alabama. The squirrel cage was originally the fan for a large air-conditioner. It was 30 inches long and 28 inches in diameter; there were 64 slightly curved vanes, each 2 inches wide. The squirrel cage was attached at its center of rotation to the end of a shaft. In tests the

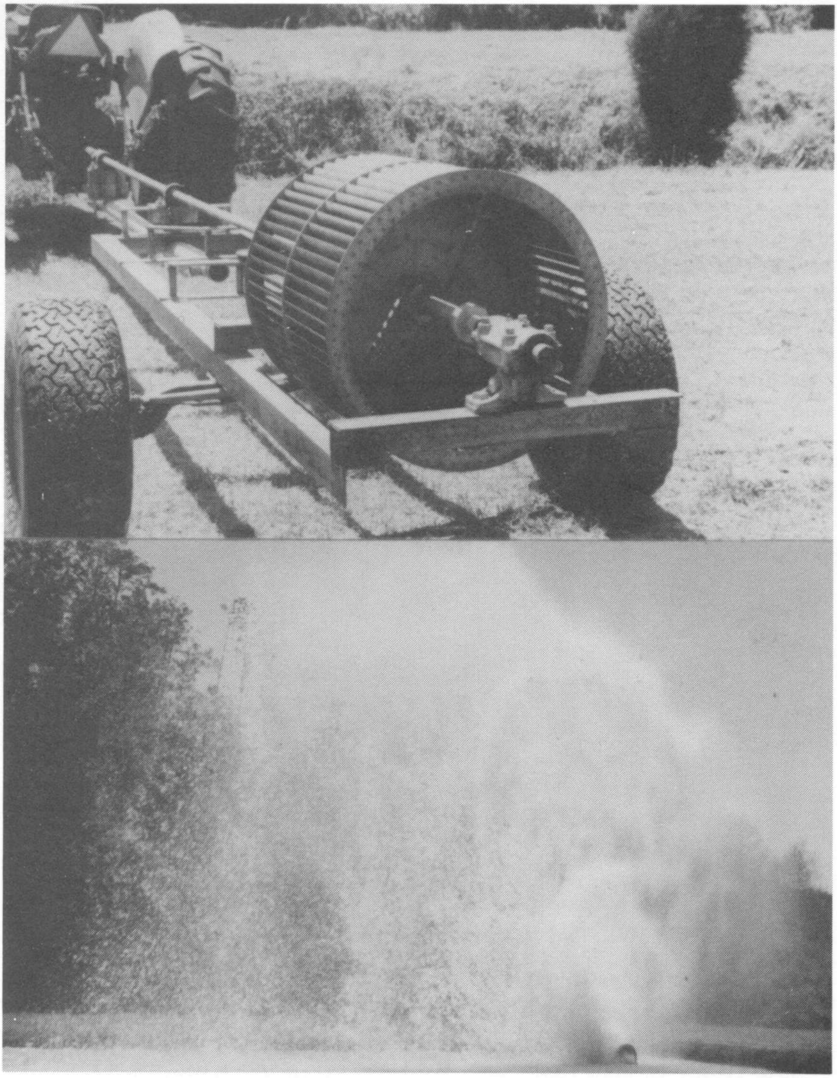

FIG. 6. McLendon tractor powered squirrel cage aerator.

back edge of the squirrel cage extended 2 inches into the water, but the front edge was not as deep because the aerator was set at an angle when backed into the pond. The 65-horsepower tractor could only rotate the aerator at 400 r.p.m. The aerator propelled water approximately 40 feet into the air.

SOTR for this aerator was 17.3 pounds of oxygen per hour, table 2.

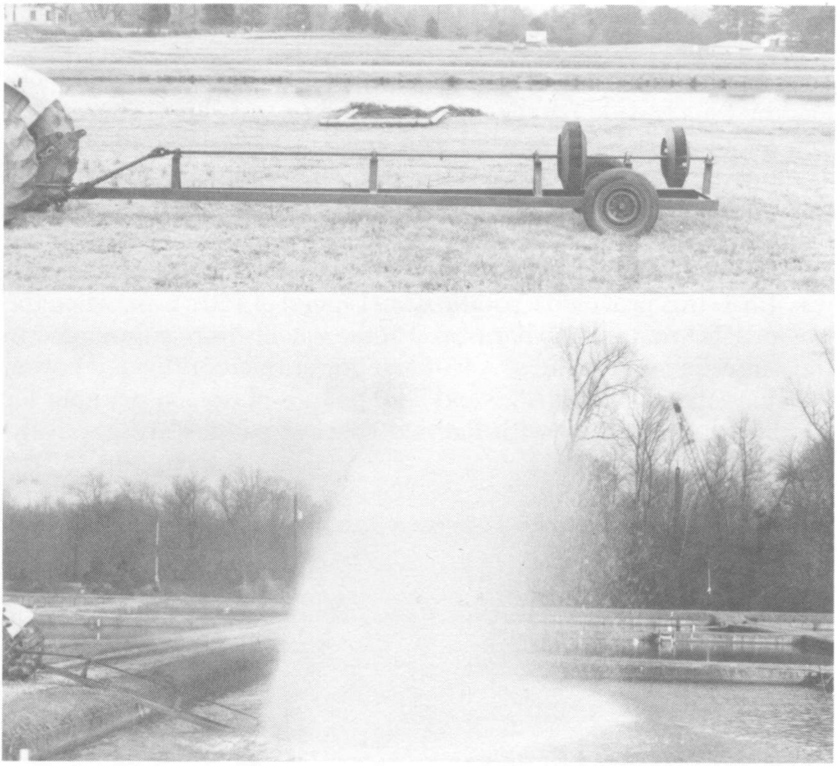

FIG. 7. McCray tractor powered squirrel cage aerator.

McCray - Harold McCray, Greensboro, Alabama, fabricated this aerator, figure 7. It consisted of two squirrel cages attached at their centers of rotation to a shaft. One squirrel cage was 24 inches in outside diameter; the other was 28 inches in outside diameter. Inside diameters were 15 and 17 inches, respectively. Vanes were tear-drop shaped in cross section. The two squirrel cages were separated by a distance of 3 feet along the shaft. The aerator was backed into the pond until the bottom edge of the squirrel cage nearest the tractor was submerged to a depth of 11 inches. The 65-horsepower tractor turned the squirrel cage at only 400 r.p.m. Water was propelled about 50 feet into the air. The SOTR for the McCray squirrel cage aerator was 37.3 pounds of oxygen per hour, table 2.

Paddle Wheel Aerators

Auburn University - The two aerators were of almost identical construction, except that one aerator had flat paddles and the other had slightly concave paddles. Aerators were constructed by local machine shops. Paddle wheels consisted of 18-inch-diameter by 18-inch-long hubs mounted on axles of truck differentials, figure 8. Twelve 14-inch-long by 6-inch-wide paddles were welded to each hub. There were four paddles, each 90° apart in each row of paddles around the hub. The middle row of paddles was rotated 45° on the circumference of the hubs to the other two rows to provide a staggered arrangement of paddles. A drive shaft connected to the truck differential was fitted at its other end with a PTO shaft. Speed reduction by the differential was 4.5:1; this provided a paddle wheel speed of 120 r.p.m. when the tractor PTO rotated at 540 r.p.m. Paddle wheels were submerged to the centerlines of the hubs. A 65-horsepower tractor provided power.

Values of SOTR were 43.3 and 58.0 pounds of oxygen per hour for paddle wheel aerators with flat and concave paddles, respectively, table 2.

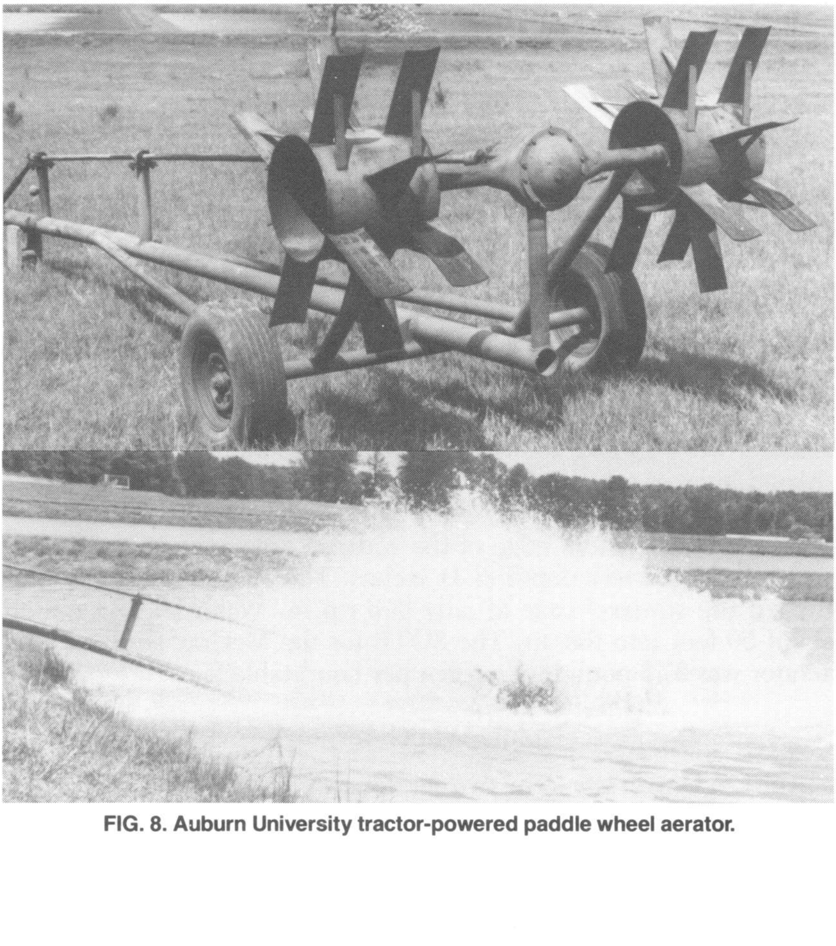

FIG. 8. Auburn University tractor-powered paddle wheel aerator.

House Manufacturing - This aerator, figure 9, was manufactured by House Manufacturing Co., Cherry Valley, Arkansas. Two 45-inch-long by 20-inch-diameter hubs were mounted on a heavy duty, 0.75-ton truck differential with a gear reduction ratio of 4.5:1. Paddles were 12-inches-long and made of 6-inch-wide x 1.5-inch-deep channel iron. The paddles were welded on each hub in six rows of four paddles per row. Each paddle in a row was 90° apart on the circumference of the hub. In the first row, the first paddle was welded at O° (360°) on the circumference of the hub. In the second row, the first

FIG. 9. House Manufacturing tractor-powered paddle wheel aerator.

paddle was welded at 15°. For the third row, the first paddle was welded at 30°. The procedure was continued for all six rows to provide a spiral arrangement of paddles. A drive shaft was connected to the differential and fitted at the other end with a PTO shaft. In tests, the paddle tips were submerged to a depth of 9.88 inches and rotated at 110 r.p.m. with a 65-horsepower tractor.

The House Manufacturing Co. paddle wheel aerator had a SOTR of 65.7 pounds of oxygen per hour, table 2.

Comparison of Tractor-Powered Aerators

Values for SOTR are summarized in table 2. Standard errors of the mean provided for SOTR values reveal that good precision was achieved in oxygen-transfer tests.

The highest SOTR was obtained for the Water Blower, but this aerator required a 200-horsepower tractor to drive it. Tractor sizes for other aerators were similar (50 to 80 horsepower). Of the three paddle wheel aerators, one had paddles of channel iron (rectangular in cross section), one had paddles concave in cross section, and one had flat paddles. All three paddle wheel aerators were powered by the same 65-horsepower tractor. The aerator with channel iron paddles had the highest SOTR value; the paddle wheel aerator with concave paddles was superior to the one with flat paddles. The Airmaster aerator had a SOTR comparable to the paddle wheel aerator with flat paddles; however, other pump sprayer and squirrel cage aerators powered by 50- and 65-horsepower tractors had lower SOTR values than paddle wheel aerators.

Busch et al. (9) tested a few tractor-powered aerators, and they also found paddle wheel aerators to have greater SOTR values than pump sprayer aerators. However, the Airmaster aerator, a pump sprayer, was equally as effective in transferring oxygen, table 2. In addition, it directs water in two directions along the shoreline. During oxygen-depletions, fish often congregate in shallow water along pond edges. The Big John aerator does not require a lot of power; it can be operated with a 35-horsepower tractor. It transfers enough oxygen to make it useful in aerating small ponds (1 to 5 acres). An attachment for the Big John aerator permits it to be used effectively in applying chemicals to fish ponds.

Gears in the differential of paddle wheel aerators serve to reduce the speed of the tractor PTO, and these gears are the major maintenance problem with paddle wheel aerators. The pump of pump sprayer aerators is driven directly by the tractor PTO and gear reduction is unnecessary. Therefore, pump sprayer aerators require less maintenance than paddle wheel aerators. In addition, the sprayer device may be removed from most pump sprayer aerators, and the pump used for pumping water. These desirable features should spur efforts to develop more efficient pump sprayer aerators.

ELECTRIC AERATORS

Electric aerators included paddle wheel, vertical pump, pump sprayer, propeller aspirator pump, and diffuser aerators. A paddle wheel aerator splashes water into the air as the paddle wheel rotates. A vertical pump aerator consists of a motor with an impeller (propeller) attached to its shaft. The impeller jets water into the air without imparting much velocity to the water. A pump sprayer aerator employs a centrifugal pump to spray water at high velocity through holes in a manifold and into the air. A propeller aspirator pump aerator uses the venturi principle to introduce air bubbles into turbulent water created by an uncased impeller. A diffuser aerator discharges fine bubbles of air into the water near the pond bottom.

Paddle Wheel Aerators

House Manufacturing - This aerator, figure 10, was fabricated by House Manufacturing Co., Cherry Valley, Arkansas. It had a 12-foot-long hub. The hub was 8.62 inches in diameter and each end was fitted with a short, 2.25-inch-diameter shaft. Paddles were 14 inches long and 6 inches wide and were triangular (120°) in cross section. There were four paddles welded 90° apart in each row around the circumference of the hub making 24 rows of paddles. The paddles were spiralled on the hub; the first paddle in each row was offset 20° from adjacent paddles to produce the spiral. A spiral paddle arrangement is illustrated in figure 11. The paddle wheel was mounted in take-up bearings, and bearings were mounted on a metal frame. The metal frame was attached to metal boxes filled with styrofoam to provide floatation. The 10-horsepower, 230/460-volt, 3-phase electric motor was connected to a gear reducer by a belt drive. The gear reducer output shaft was attached to the aerator shaft with a flexible coupling.

The aerator was operated at 84 r.p.m. and at three paddle depths: 3.25, 3.62, and 4.0 inches. The motor was fully loaded at a paddle depth of 3.62 inches, table 3. At a paddle depth of 3.62 inches, SOTR and SAE were 48.1 pounds of oxygen per hour and 4.8 pounds of oxygen per horsepower-hour, respectively.

Geddie's Machine and Repair Shop - The aerator, which was manufactured by Geddie's Machine and Repair Shop, Hollandale, Mississippi, had a 12-foot-long x 8-inch-diameter hub which had

TABLE 3. PERFORMANCE DATA ON FLOATING ELECTRIC PADDLE WHEEL AERATORS TESTED

Aerator	Design Features				Power Consumption	Power at aerator shaft	SOTR[1]	SAE[2]	Operating costs[3]	
	Hub length	Diameter	Speed	Depth					Per hr.	Per lb. O_2
	Ft.	*In.*	*r.p.m.*	*In.*	*Kw*	*hp*	*Lb. O_2/hr.*	*Lb. O_2/hp-hr.*	*Dol.*	*Dol.*
House	12	36	84	3.25	9.04	9.12	38.3 ± 1.4	4.2	0.68	0.018
	12	36	84	3.62	9.44	10.0	48.1 ± 0.2	4.8	.71	.015
	12	36	84	4.0	10.58	11.4	51.3 ± 4.0	4.5	.79	.015
Geddie	12	32	89	4.25	8.18	9.2	41.4 ± 0.1	4.5	.61	.015
Dan	10	37	108	2.75	5.61	6.4	22.4 ± 0.2	3.5	.42	.019
Martar	12	36	67	4.0	7.76	8.6	39.9 ± 1.1	4.6	.58	.015
	12	36	78	4.0	9.46	10.0	44.4 ± 1.6	4.4	.71	.016
S and N	10.5	37.5	83	7.5	8.60	8.55	42.0 ± 1.5	4.9	.60	.014
	10.5	37.5	98	5.5	8.62	8.55	36.3 ± 1.6	4.2	.60	.107
	10.5	37.5	120	3.0	8.41	8.40	29.6 ± 2.5	3.5	.59	.020
Beaver Tail	4.0	32	150	6.0	9.43	9.00	20.5 ± 1.1	2.3	.71	.035
	4.0	32	190	3.0	9.70	9.30	16.7 ± 1.3	1.8	.70	.042
Rogers	6	34	78	8.0	7.15	7.5	16.5 ± 1.2	2.2	.54	.033
Spree	4	46	110	6.0	9.83	10.0	19.4 ± 1.0	1.9	.74	.038
Fritz	2	24	109	3.5	2.09	2.0	5.4 ± 0.2	2.7	.16	.030
AEMCO, PVC	10	32	105	8.0	9.69	10.0	28.4 ± 0.5	2.8	.73	.026
	15	32	110	4.5	9.48	10.0	20.0 ± 0.2	2.0	.71	.036
	15	32	110	3.5	7.85	7.5	26.5 ± 0.7	3.5	.59	.022
AEMCO, Steel	12	32	79	4.5	9.18	8.8	43.1 ± 0.9	4.9	.69	.016

[1] Standard oxygen transfer rate.

[2] Standard aeration efficiency; SOTR divided by power applied to aerator shaft.

[3] Based on electricity cost of $0.075 per kilowatt-hour. Demand changes for electricity were not used in computing operating costs in any aerator test.

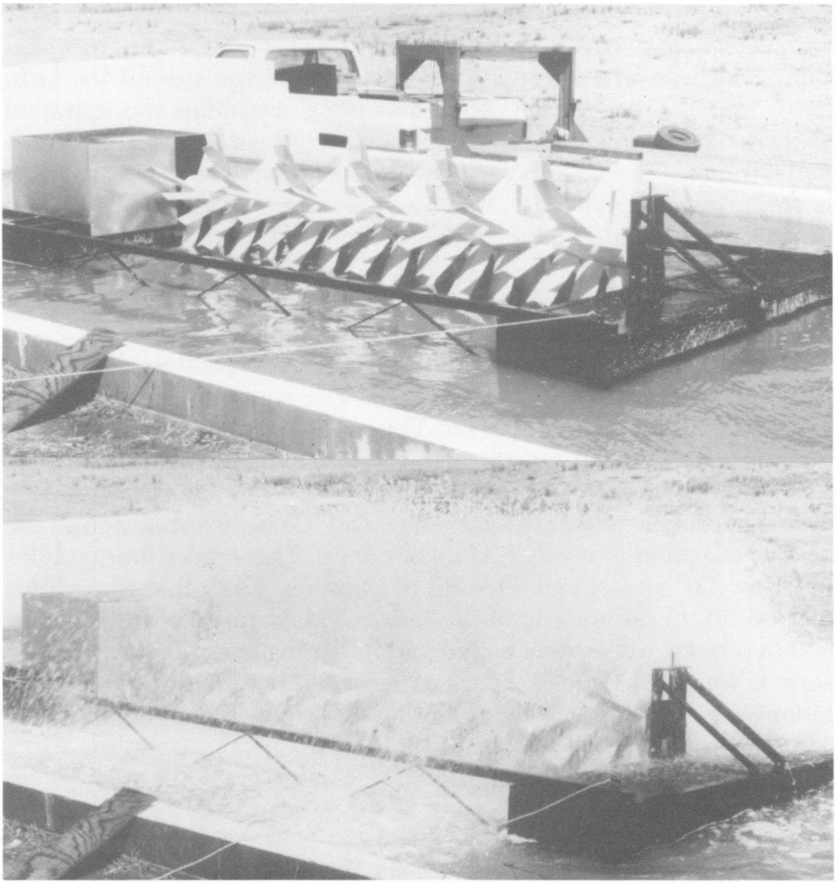

FIG. 10. House Manufacturing electric paddle wheel aerator.

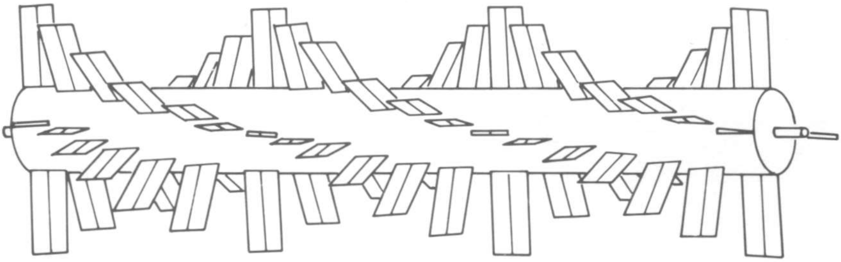

FIG. 11. Spiral arrangement of paddles on hub.

short, 1.5-inch-diameter shafts at each end, figure 12. Paddles were 12 inches long x 4.75 inches wide and triangular (120°) in cross section. Paddles were welded 90° apart in each row around the hub; there were 23 rows. Each of the four lines of paddles was spiralled slightly. The paddle wheel was supported in bearings mounted on a metal frame. Fiberglass boxes provided flotation. The motor was a 10-horsepower, 230/460-volt, 3-phase gearmotor. Paddle wheel speed was 89 r.p.m., and paddle submergence was 4.25 inches.

The motor was slightly under loaded (9.2 horsepower). SOTR and SAE values were 41.4 pounds of oxygen per hour and 4.5 pounds of oxygen per horsepower-hour, respectively, table 3.

Dan's Mechanics - This aerator, figure 13, was produced by Dan's Mechanics, Morgan City, Mississippi. The aerator hub was 10 feet long and 6.75 inches in diameter. The hub was welded to a 1.75-inch-diameter shaft which ran through the hub. Paddles were 15 inches long and trapezoidal in cross section. The trapezoidal section was 4.25 inches wide across the open face and 3.5 inches wide across the back of the paddle; it was 1.25 inches deep. There were four paddles per row (90° apart) and 24 rows of paddles. Each line of paddles dipped 90° to the middle of the hub and then rose 90° to the other end to provide a chevron-shaped paddle arrangement, figure 13. The aerator was supported in bearings mounted on a metal frame. Flotation was provided by water-tight metal boxes. The 10-horsepower,

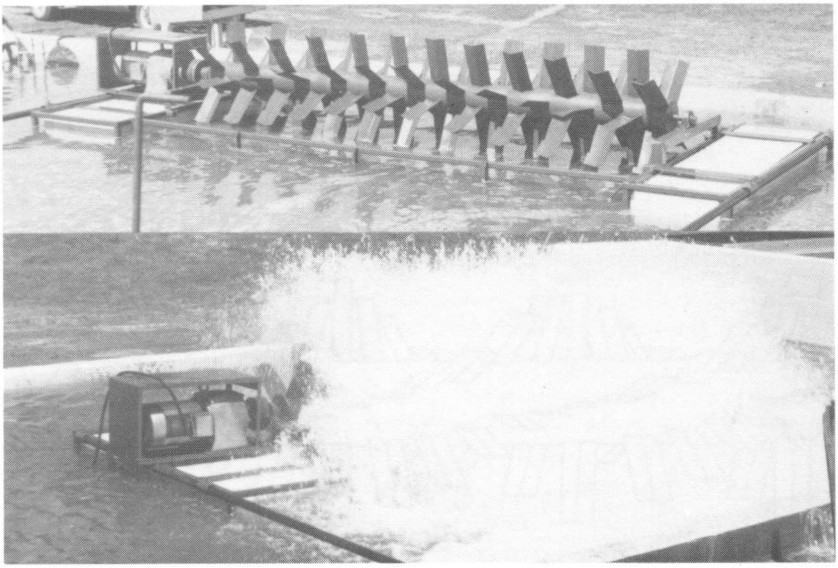

FIG. 12. Geddie's Machine and Repair Shop electric paddle wheel aerator.

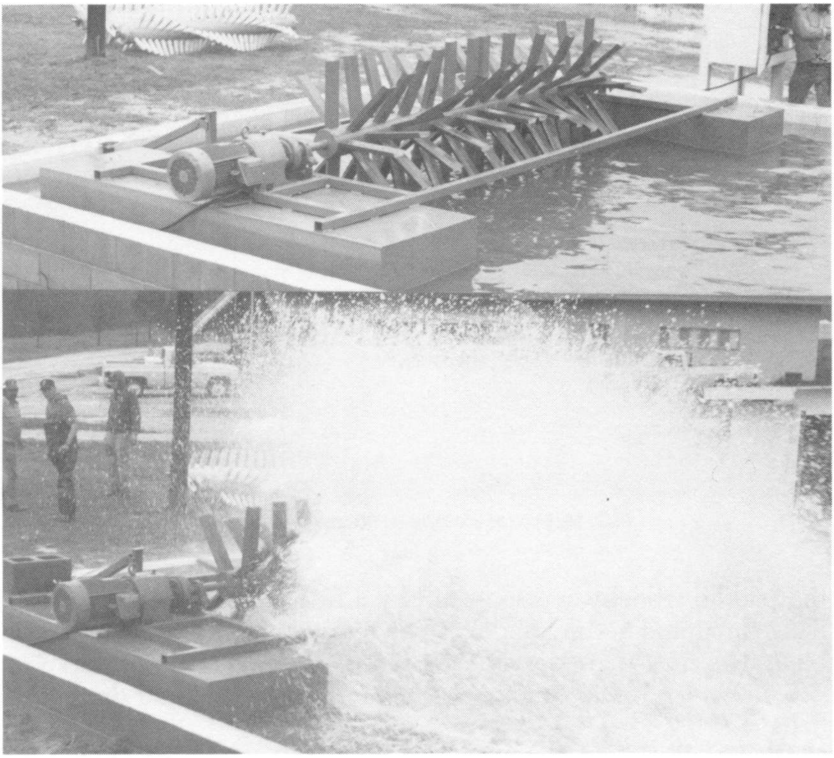

FIG. 13. Dan's Mechanics electric paddle wheel aerator.

230/460-volt, 3-phase gearmotor was connected to the aerator shaft with a flexible coupling. Paddle wheel speed was 108 r.p.m., and the paddle submergence depth was 2.75 inches.

The paddle depth was not sufficient to properly load the motor at a paddle wheel speed of 108 r.p.m. Power applied to the aerator shaft was estimated at 6.4 horsepower, table 3. Values for SOTR and SAE were 22.4 pounds of oxygen per hour and 3.5 pounds of oxygen per horsepower-hour, respectively.

Martar - The aerator, figure 14, was built by Martar Brothers, Lake Village, Arkansas. The hub was 12 feet long and 8 inches in diameter with 1.5-inch-diameter shafts at each end. Paddles were 14 inches long, 5.5 inches wide, and triangular (127°) in cross section. There were four paddles per row (90° apart) and 23 rows. Each line of paddles was spiralled slightly from each end to the middle of the hub to produce a chevron-shaped paddle arrangement. The metal aerator support frame was attached to styrofoam floats. One end of

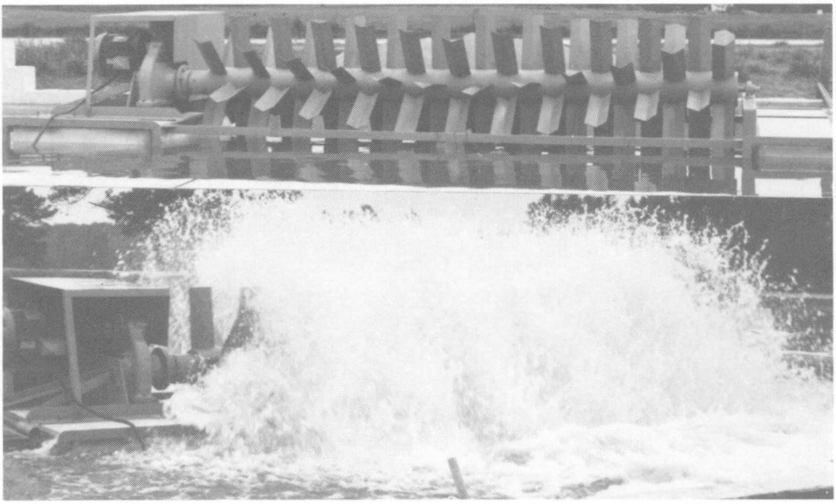

FIG. 14. Martar electric paddle wheel aerator.

the paddle wheel was supported by a bearing. The other end was flange mounted to the spindle of a final drive from a John Deere combine. The final drive served as a gear reducer. The 10-horsepower, 230/460 volt, 3-phase motor was connected to the final drive with belts.

The paddle wheel was operated at a paddle depth of 4 inches and at 67 or 78 r.p.m. A greater SOTR (44.4 pounds of oxygen per hour) was obtained for 78 r.p.m., and the motor operated near full load at this paddle wheel speed, table 3. Values for SAE were 4.6 pounds of oxygen per horsepower-hour at 67 r.p.m. and 4.4 pounds of oxygen per horsepower-hour at 78 r.p.m.

S and N Sprayer - The aerator, figure 15, was constructed by the S and N Sprayer Co., Greenwood, Mississippi. The hub was 10.5 feet long and 8 inches in diameter. Paddles, figure 16, were pressed from sheet metal. They were 3 inches wide and of polygonal cross-section. Tips were flat and bent at a 22.5° angle. Paddles were either 10.75 or 13.75 inches long. Hence, maximum paddle wheel diameter was 37.5 inches. Paddles were welded to the hub with four paddles 90° apart in each row around the hub circumference. Paddles in adjacent rows were welded on 4.5-inch centers. Progressing from one end of the hub to the other, paddles in each row were attached 1.02 inches further around the circumference of the hub in the same direction of rotation to produce a spiral. Paddles were attached in alternating rows of long (13.75 inches) and short (10.75 inches) paddles. A short, 1.5-

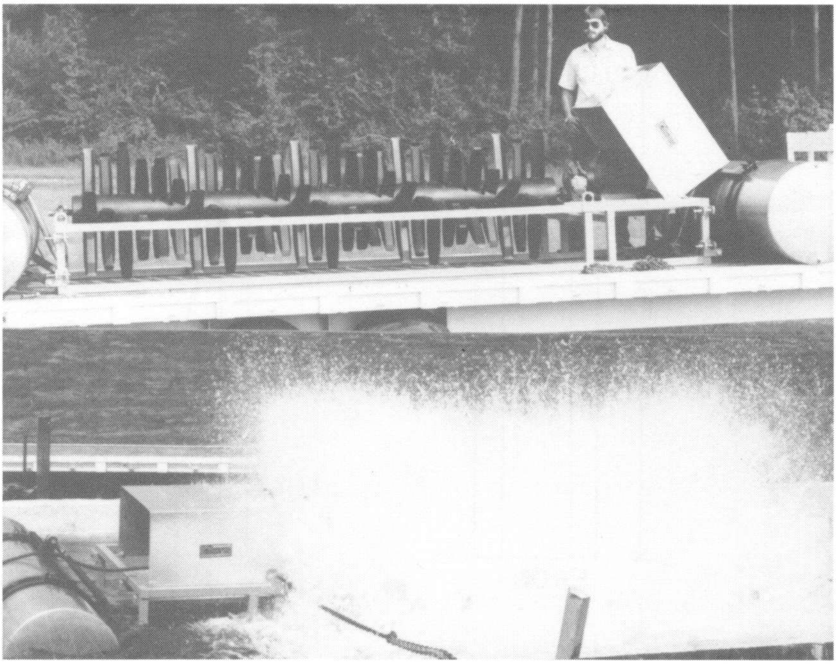

FIG. 15. S and N Sprayer electric paddle wheel aerator.

inch-diameter shaft at the outside end of the hub fit into a pillow block bearing. The bearing was mounted to a 2-inch-square tubing frame. A 1.75-inch-diameter shaft was mounted on the drive end of the hub and attached directly to the gear reducer. The gear reducer was connected by belt drive to a 10-horsepower, 3-phase, 230/460 volt, electric motor. The metal frame was attached at each end to 8-foot-long by 29-inch-diameter aluminum tanks. Attachment was with rods through holes which permitted the frame to be raised or lowered with turnbuckles. Thus, paddle depth could be regulated.

Tests were conducted at three paddle wheel speeds: 83, 98, and 120 r.p.m. At these speeds, paddle depths for long paddles were 7.5, 5.5, and 3.0 inches, respectively. The greatest SOTR (42.0 pounds of oxygen per hour) and SAE (4.9 pounds of oxygen per horsepower-hour) were achieved when the paddle wheel was rotated at 83 r.p.m. with 7.5-inch paddle depth, table 3.

Rogers - The aerator depicted in figure 17 was constructed by Willie Rogers, Ralph, Alabama. The aerator hub was 6 feet long and 8.5 inches in diameter. The hub was fitted with 1.5-inch-diameter shafts. Paddles were of angle iron which was 2.75 inches wide across the open face; they were 12.75-inches long. There were three paddles

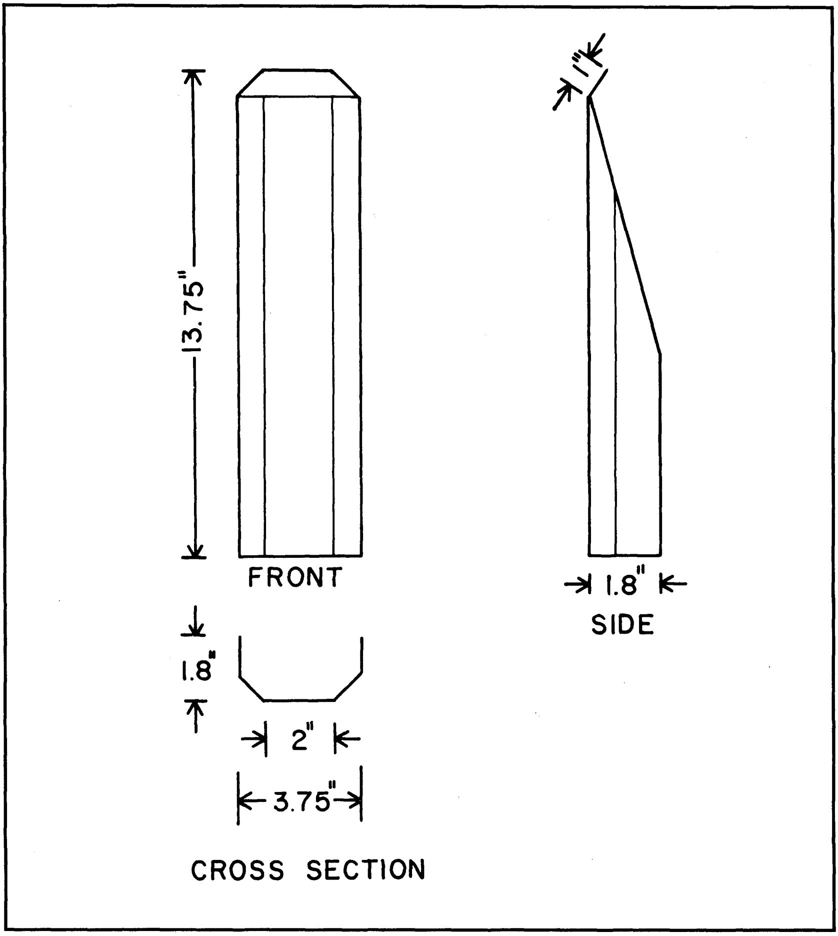

FIG. 16. Long paddle for S and N Sprayer aerator.

per row, so paddles were 120° apart around the circumference of the hub, making 25 rows. Each line of paddles was spiralled slightly. The motor was 7.5-horsepower, 220-volt, and single-phase; it was connected to the gear reducer unit by belts. The gear reducer was joined directly to the aerator shaft. Bearings which supported the paddle wheel were attached to an angle iron frame which was positioned on styrofoam floats. Paddle depth was 8 inches, and the paddle wheel speed was 78 r.p.m.

SOTR and SAE were 16.5 pounds of oxygen per hour and 2.2 pounds of oxygen per horsepower-hour, respectively, table 3.

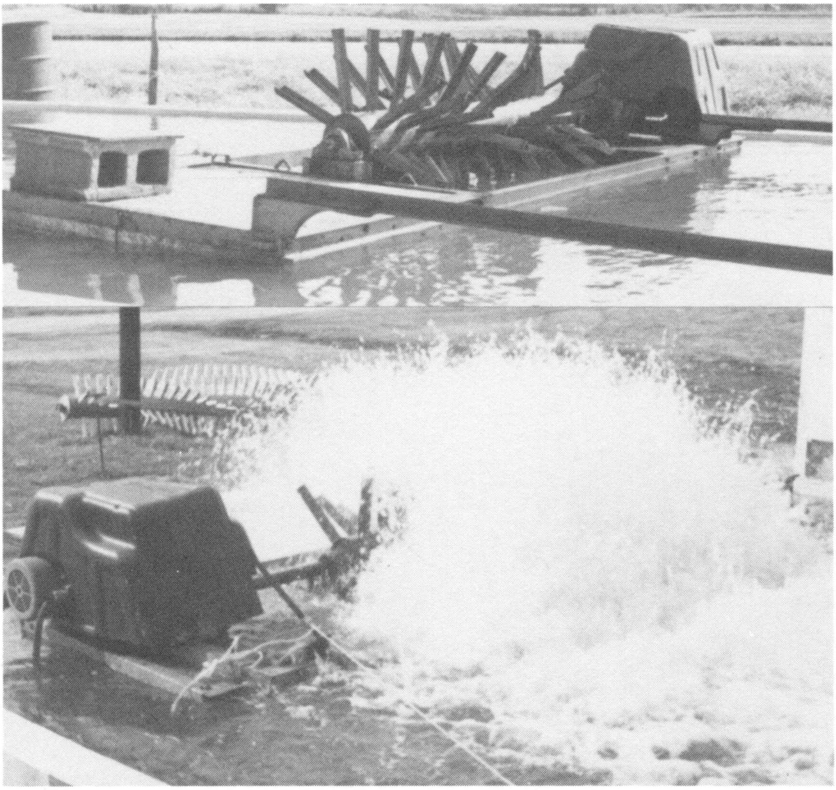

FIG. 17. Rogers electric paddle wheel aerator.

Spree Aerator - Thed Spree of Boligee, Alabama, fabricated the aerator shown in figure 18. The aerator was constructed from a truck differential and axles attached to an angle iron frame and floated with styrofoam blocks. Hubs, each 2 feet long and 16 inches in diameter, were attached to the axles. Paddles were of angle iron (interior angle of 162°) which was 6 inches wide across the open face and 15 inches long. There were four paddles per row (90° apart) and 4 rows of paddles per hub in a staggered arrangement. The 10-horsepower, 220 volt, single-phase motor was connected by a belt drive to the differential drive shaft. Paddle depth was 6 inches, and paddle wheel speed was 110 r.p.m.

Respective values for SOTR and SAE were 19.4 pounds of oxygen per hour and 1.9 pounds of oxygen per horsepower-hour, table 3.

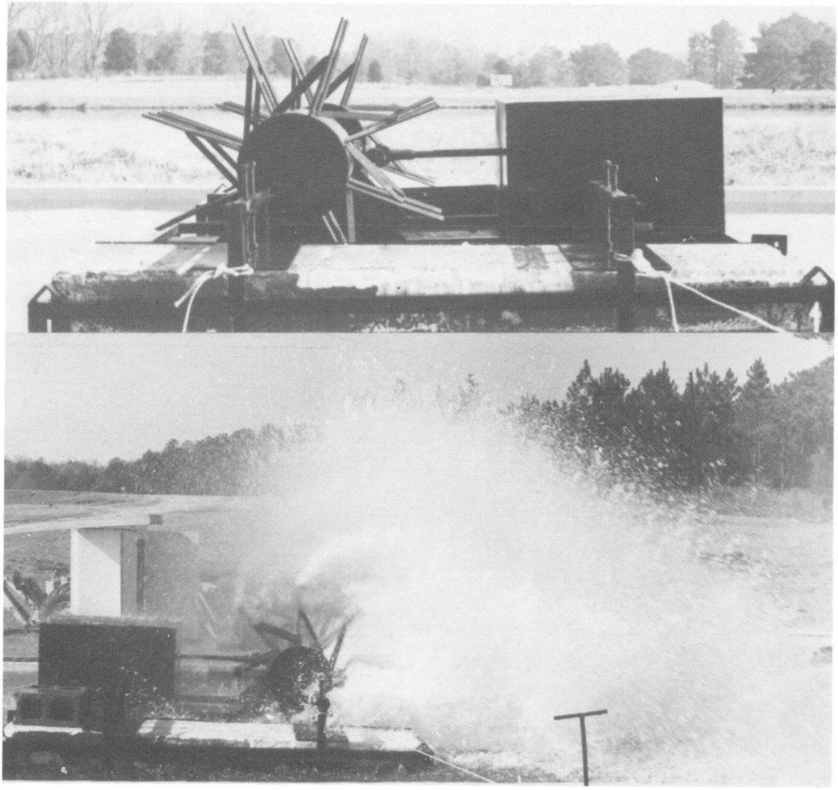

FIG. 18. Spree electric paddle wheel aerator.

Beaver Tail - This aerator was manufactured by the Beaver Tail Manufacturing Co., Selma, Alabama. An Impala Chevrolet differential with a 3:1 speed reduction ratio was attached to an angle iron frame which rested on styrofoam floats, figure 19. Hubs (20 inches in diameter by 24 inches long) were attached to the axles of the differential. Six, 24-inch-wide by 6-inch-long paddles were welded to each hub to form two, 24-inch-long by 32-inch-diameter paddle wheels. A drive shaft from the differential was belt driven by a 10-horsepower, single-phase, 220-volt motor.

The paddle wheel aerator was tested at two operating conditions: 190 r.p.m. and 3-inch paddle depth or 150 r.p.m. and 6-inch paddle depth. Best results were achieved at 150 r.p.m. (SOTR = 20.5 pounds of oxygen per hour; SAE = 2.3 pounds of oxygen per horsepower-hour), table 3.

Fritz - This aerator was sold in the United States by Fritz Chemical Co., Dallas, Texas, but it was manufactured by the Nan Rong Fishing

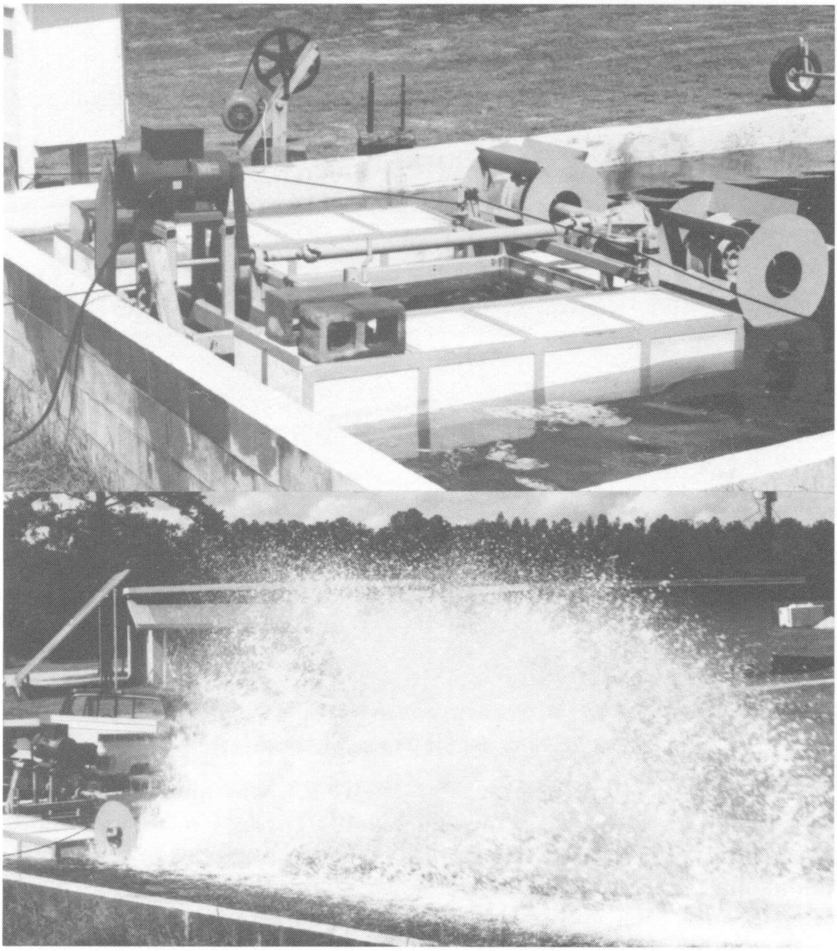

FIG. 19. Beaver Tail electric paddle wheel aerator.

Machinery Co., Tainan Hsiang, Taiwan. Brief description of the aerator, figure 20, is difficult. It consisted of four plastic paddle wheels mounted two each on two stainless steel shafts. Each paddle wheel was 24 inches in diameter and was comprised of four, 6-inch-wide, flat paddles. The 2-horsepower, 110/220 volt, single-phase motor was coupled to a gear reducer which, in turn, was coupled to the shafts. Paddle wheels rotated at 109 r.p.m. with a paddle tip submergence of 3.5 inches.

The Fritz aerator had an SOTR of 5.4 pounds of oxygen per hour and an SAE of 2.7 pounds of oxygen per horsepower-hour, table 3.

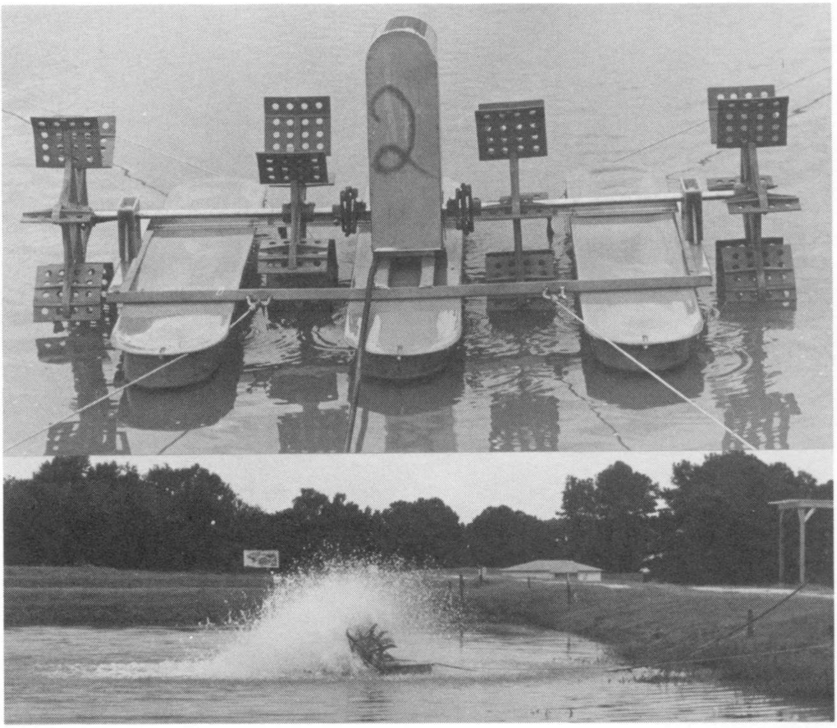

FIG. 20. Fritz electric paddle wheel aerator.

AEMCO - This unique aerator, figure 21, was manufactured by the Aquacultural Engineering and Manufacturing Co., Greenwood, Mississippi. The hub consisted of PVC pipe (10 inches in diameter). Short shafts were attached to flanges, and a flange and shaft were pressed into each end of the pipe and secured with bolts. Paddles consisted of 3.5-inch diameter PVC pipe (32 inches long) which had been cut longitudinally and at an angle on each end. Paddles were inserted through holes in the hub and secured with pop rivets. Cut ends of the pipes served as paddles. Paddles spiralled slightly around the hub. The floatation assembly was fabricated from fiberglass and filled with foam. The motor was a 230/460 volt, 3-phase, gearmotor. Three aerators were tested. One had a 10-horsepower motor and a 10-foot-long hub with 66 paddles; rotation speed was 105 r.p.m. with a paddle depth of 8 inches. The other two aerators had 15-foot-long hubs with 98 paddles. Both aerators had paddle wheel speeds of 110 r.p.m. but one had a 7.5-horsepower motor and the other had a 10-horsepower motor; paddle depths were 3 inches and 4.5 inches, respectively.

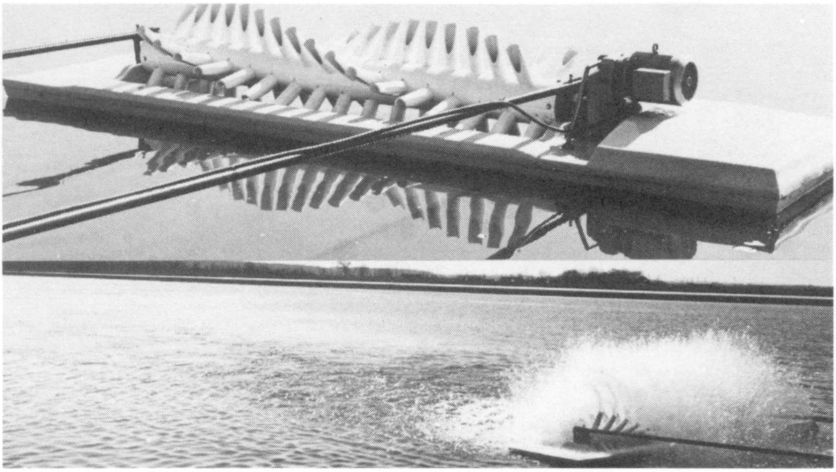

FIG. 21. AEMCO plastic (PVC) electric paddle wheel aerator.

Best results (SOTR = 26.5 pounds of oxygen per hour; SAE = 3.5 pounds of oxygen per horsepower-hour) were achieved with the 15-foot-long PVC paddle wheel operated at 3.5-inch paddle depth and 110 r.p.m., table 3, but a 15-foot-long PVC paddle wheel is impractical. The 10-foot-long PVC paddle wheel had an SOTR of 28.4 pounds of oxygen per hour and an SAE of 2.8 pounds of oxygen per horsepower-hour.

Since these tests were run, AMECO has started manufacturing a paddle wheel aerator with a steel hub and paddles. The paddle wheel is similar to the one illustrated in figure 11. Values for SOTR and SAE were 43.1 pounds of oxygen per hour and 4.9 pounds of oxygen per horsepower-hour, respectively. Hence, the AEMCO aerator with steel paddle wheel is highly efficient.

Vertical Pump Aerators

Air-o-later - This aerator, figure 22, is manufactured by Air-o-later Corporation, Kansas City, Missouri. The submersible motor and impeller were attached in the center of a hole within a molded polystyrene float. A diffuser was mounted above the motor and impeller assembly. The impeller turned at 3,450 r.p.m. and jetted water through the hole in the float and the diffuser produced a circular discharge pattern. The Air-o-later is available in 0.33 and 1.0-horsepower sizes; tests were made for a 0.33-horsepower unit. The 0.33-horsepower units have 110-volt, single-phase motors.

Values for SOTR and SAE were 0.7 pound of oxygen per hour and 2.2 pounds of oxygen per horsepower-hour, respectively, table 4.

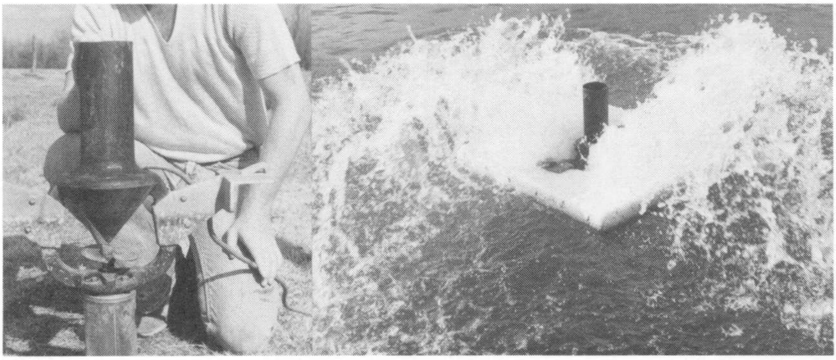

FIG. 22. Air-o-later vertical pump aerator.

TABLE 4. PERFORMANCE DATA ON FLOATING, ELECTRIC, VERTICAL-PUMP AERATORS TESTED

Aerator	Power consumption	Power at aerator shaft	SOTR[1]	SAE[2]	Operating costs[3]	
	Kw	*hp*	*Lb.* O_2*/hr.*	*Lb.* O_2*/hp-hr.*	*Dol.*	*Dol.*
Air-o-later	0.33	0.33	0.7 ± 0.1	2.2	0.025	0.036
Otterbine	1.86	2.0	4.6 ± 0.2	2.3	.14	.030
	2.79	3.0	6.6 ± 0.3	2.2	.21	.032
Dyer	10.64	10.0	24.0 ± 0.9	2.4	.80	.033
Ice Eater	.70	0.75	1.9 ± 0.1	2.5	.05	.026
McDonald	.68	0.75	1.4 ± 0.1	1.9	.05	.036
Rogers	1.98	2.0	2.4	1.2	.15	.062

[1] Standard oxygen transfer rate.

[2] Standard aeration efficiency; SOTR divided by power applied to aerator shaft.

[3] Based on electricity cost of $0.075 per kilowatt-hour.

Otterbine - The Otterbine, manufactured by Rodale Resources, Emmaus, Pennsylvania, consisted of a submersible motor and impeller mounted in a donut-shaped plastic float, figure 23. No diffuser was used, and water simply jetted into the air. Otterbine aerators are manufactured in several sizes; 2 and 3-horsepower units were tested. The 2-horsepower unit had a 110/120-volt single-phase motor. The 3-horsepower unit had a 230/460 volt, 3-phase motor. Motors operated at 1,750 r.p.m.

The efficiency of the 2- and 3-horsepower Otterbine aerators was essentially the same (2.2 and 2.3 pounds of oxygen per hour). Of course, SOTR was greater for the 3-horsepower aerator, table 4.

Power House - The Power House, Baltimore, Maryland, originally produced this device, figure 24, as a deicer for boat houses. It consisted of a 0.75-horsepower, submersible, 110/220 volt, single-phase, 3,400 r.p.m. motor and plastic impeller mounted inside a plastic shroud. The shroud was mounted inside a plastic floatation unit.

FIG. 23. Otterbine vertical pump aerator.

Water was jetted into the air and no diffuser was used.

The Power House had a SOTR of 1.9 pounds of oxygen per hour and a SAE of 2.5 pounds of oxygen per horsepower-hour, table 4.

Dyer - This aerator, figure 25, was manufactured by Dyer Well and Irrigation Service, Greenwood, Mississippi. The 10-horsepower, 230/460 volt, 3-phase motor was mounted above the floatation system which consisted of a square frame made of 10-inch diameter PVC pipe. The motor was positioned above a cone-shaped diffuser and a 10-inch-diameter aluminum pipe extended 2 feet below the water level to the pump bowls. The motor shaft extended to the pump bowl and the impeller was an 8.5-inch-diameter, 1.3-pitch propeller. Impeller speed was 1,750 r.p.m.

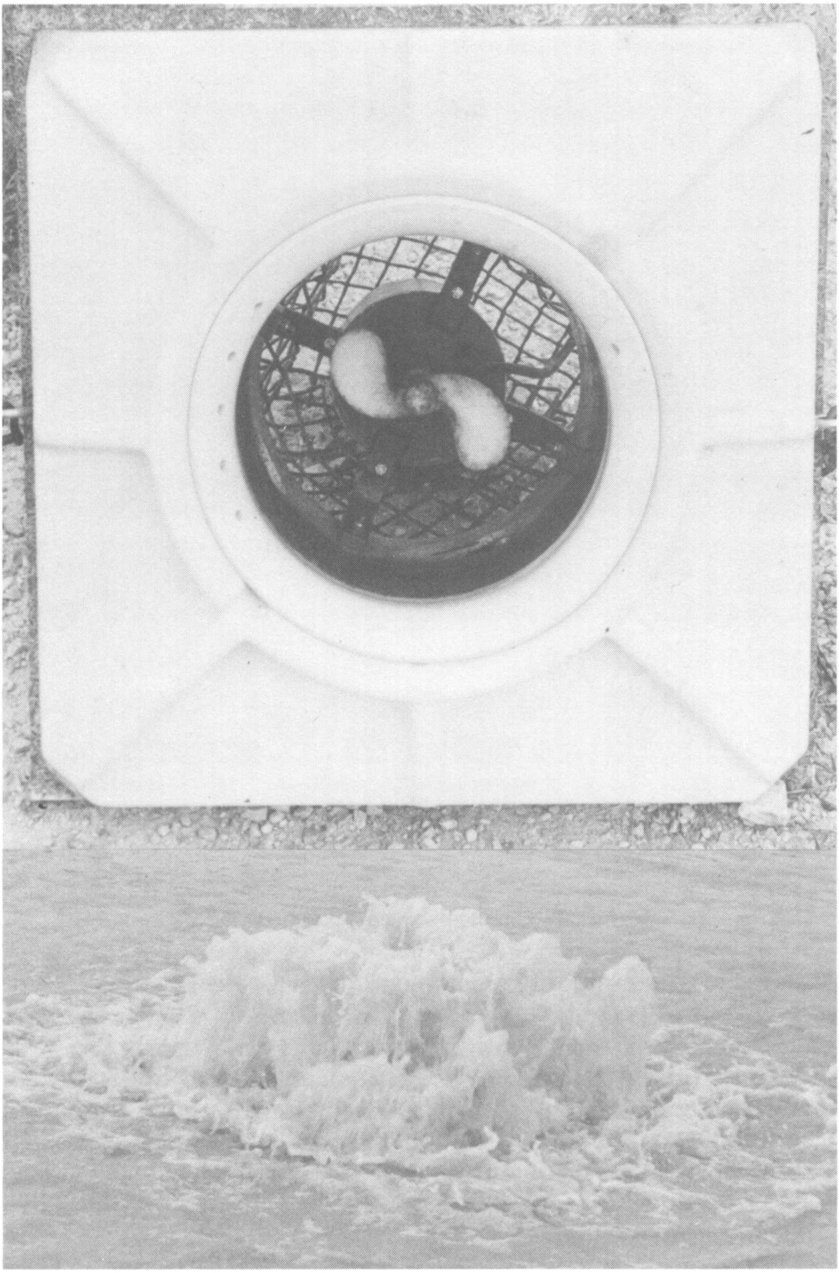

FIG. 24. Power House vertical pump aerator.

The Dyer aerator had a SOTR of 24.0 pounds of oxygen per hour and an SAE of 2.4 pounds of oxygen per horsepower-hour, table 2.

Rogers - This aerator, figure 26, was built by Willie Rogers, Ralph, Alabama. The 2-horsepower, 110/220 volt, single-phase motor was supported by a metal frame which was attached to and extended above the styrofoam float. A shaft connected the propeller to the output shaft of the motor which turned the propeller at 3,400 r.p.m.

This aerator had SOTR and SAE values of 2.4 pounds of oxygen per hour and 1.2 pounds of oxygen per horsepower-hour, respectively, table 4.

FIG. 25. Dyer vertical pump aerator.

McDonald - The McDonald Co., Erin, Tennessee, manufactured this aerator (no picture available). It consisted of a 110-volt, single-phase, 0.75-horsepower, 3,450 r.p.m. motor mounted above a housing of PVC pipe. Water intake slots were cut in the housing. The impeller was fitted into the housing and attached to the motor shaft. A 2-inch-diameter PVC discharge pipe from the bottom of the housing extended about 1 foot above the water surface. The aerator was mounted on a styrofoam float. The device simply sprayed water into the air.

Respective SOTR and SAE values were 1.4 pounds of oxygen per hour and 1.9 pounds of oxygen per horsepower-hour, table 4.

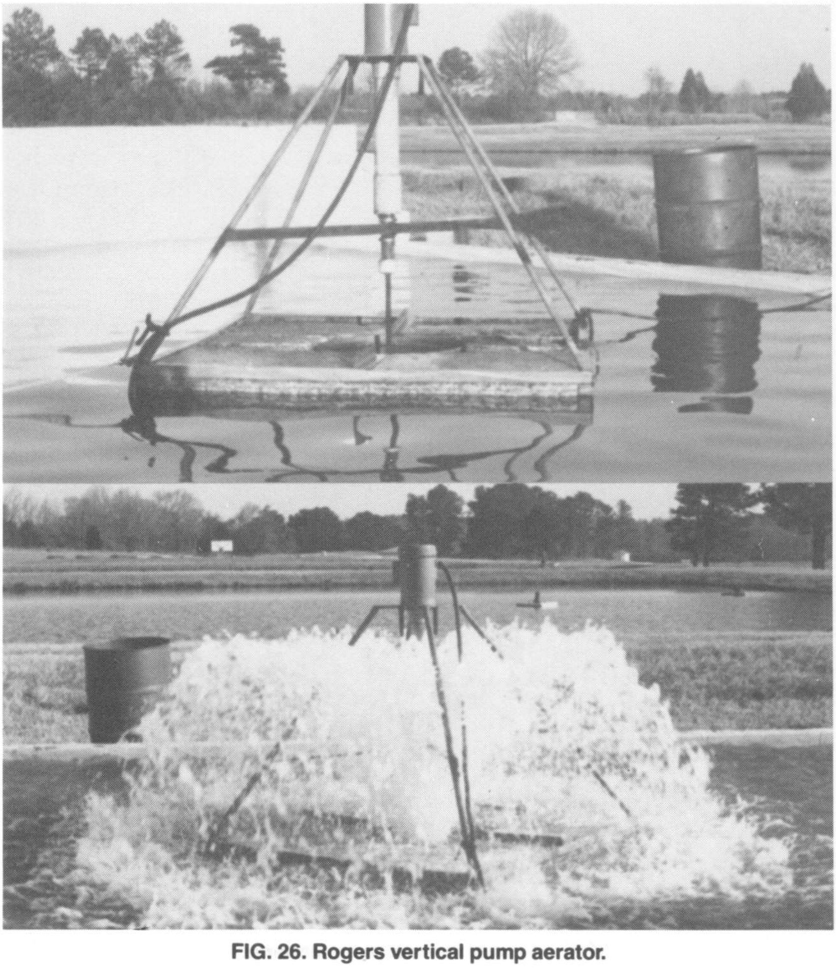

FIG. 26. Rogers vertical pump aerator.

Pump Sprayer Aerators

Airmaster - The aerator, figure 27, was manufactured by Mastersystems, Inc., Greenwood, Mississippi. The aerator was essentially the same as the trailer-mounted, tractor-powered Airmaster aerator (described under tractor-powered aerators) except that the pump and manifold were mounted on floats and the pump powered by a 10-horsepower, 230/460-volt, 3-phase electric motor. The pump shaft was connected to the motor output shaft by pulleys and belts. The pump had a 16-inch-diameter by 4-inch-wide double intake impeller that was rotated at 582 r.p.m. The 10-inch-diameter discharge manifold had one 6-inch-diameter hole in each end and four rows of discharge ports along the top.

The Airmaster had a SOTR of 32.0 pounds of oxygen per hour and a SAE of 3.2 pounds of oxygen per horsepower-hour, table 5.

Water Master - This aerator, figure 28, was fabricated by the Irrigation Equipment Co., Indianola, Mississippi. A 20-horsepower, 230/460-volt, 3-phase motor and deep well turbine pump were inserted into a 10-inch-diameter section of PVC pipe. One end of the pipe was fitted with a screen and the other end was fitted with a 45°

TABLE 5. PERFORMANCE DATA ON FLOATING, ELECTRIC, PUMP SPRAYER AERATORS TESTED

Aerator	Power consumption	Power at aerator shaft	SOTR[1]	SAE[2]	Operating costs[3]	
	Kw.	*hp*	*Lb. O_2/hr.*	*Lb. O_2/hp-hr.*	*Dol.*	*Dol.*
Airmaster	7.6	10.0	32.0	3.2	0.57	0.018
Water Master ...	15.2	16.3	26.4 ± 2.2	1.6	1.14	0.043
House	18.9	20.0	29.8 ± 0.8	1.5	1.42	0.048

[1] Standard oxygen transfer rate.

[2] Standard aeration efficiency; SOTR divided by power applied to aerator shaft.

[3] Based on electricity cost of $0.075 per kilowatt-hour.

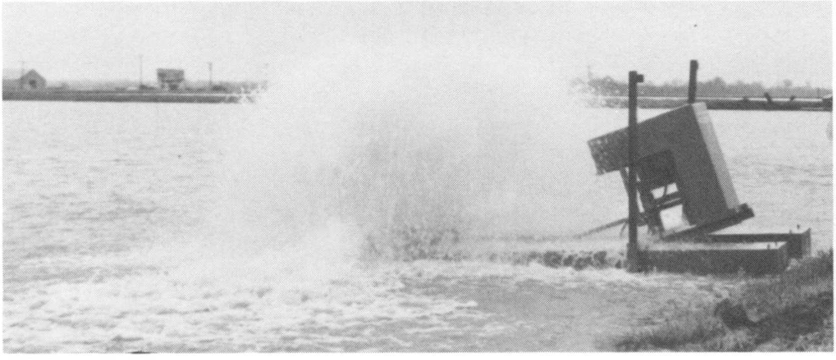

FIG. 27. Airmaster pump sprayer aerator.

elbow and a short piece of pipe was inserted into the elbow. A tee-shaped manifold was attached to the short piece of pipe. The manifold was drilled with 18, 1-inch-diameter holes. The entire device comprised the pump sprayer, and it was suspended by brackets from two, capped, 10-inch-diameter PVC pipes which served as floats. When placed in the water, the manifold extended a few inches above the surface. In operation, the pump forced water through the holes in the manifold. The pump was rated at 1,400 g.p.m. at 45-foot-head, but the actual discharge of the aerator could not be calculated because the head was not known.

Because the aerator was large, it had a high SOTR, but its efficiency was low (SAE = 1.6 pounds of oxygen per horsepower-hour), table 5.

FIG. 28. Water Master electric pump sprayer aerator.

House - This floating pump sprayer aerator, figure 29, was fabricated by House Manufacturing Co., Cherry Valley, Arkansas. The centrifugal pump had an 18-inch-diameter impeller, and it was driven by a 20-horsepower, 230/460-volt, 3-phase motor. Water was discharged through two, 10-inch-diameter, galvanized iron pipes. Each pipe was capped, and each cap contained a 4.5-inch-diameter outlet hole. Twenty-eight 0.125-inch slits were cut halfway through the pipes. The pump was rated at 3,400 g.p.m. at 14-foot head, but the actual aerator discharge could not be calculated. The pump sprayer assembly was mounted on styrofoam floats.

This aerator also had a high SOTR (29.8 pounds of oxygen per hour), but the SAE of 1.5 pounds of oxygen per horsepower-hour was low, table 5.

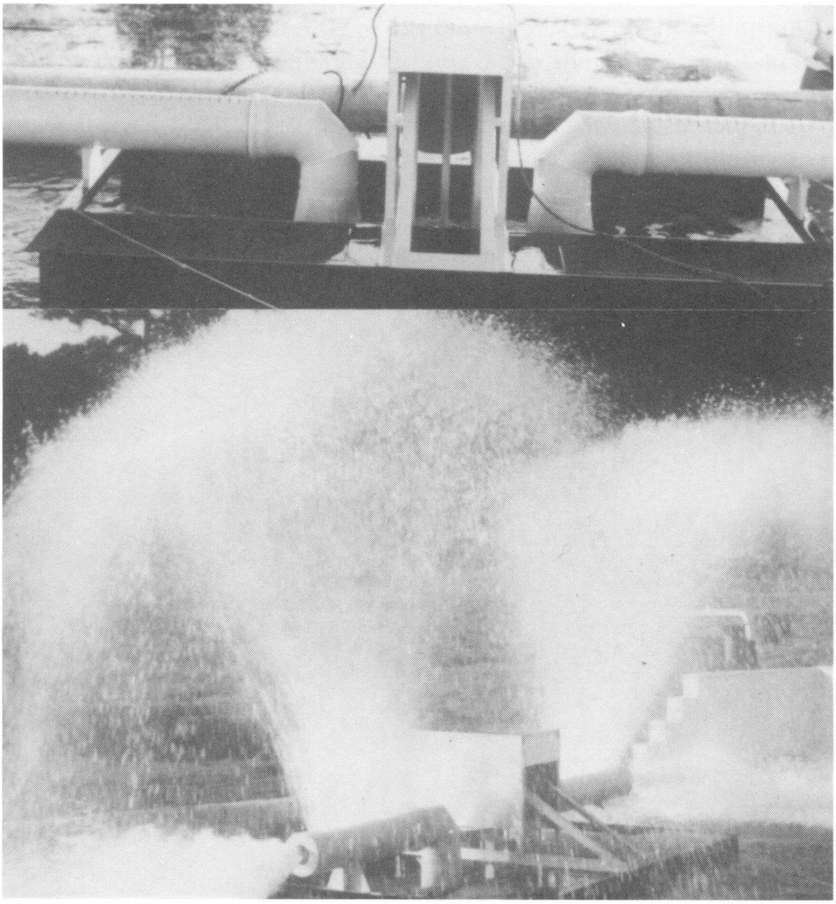

FIG. 29. House electric pump sprayer aerator.

Propeller Aspirator Pump Aerators

Aeration Industries, Chaska, Minnesota, manufactured the Aire-0_2 aerators, figure 30. The primary aerator parts were a motor, a hollow shaft which rotated at 3,450 r.p.m., a hollow housing inside which the rotating shaft fit, and an impeller which was attached at the end of the rotating shaft. Aerators were supported on pontoons or PVC floats with the motor above the water surface. In operation the impeller accelerated the water to a velocity high enough to cause a drop in pressure within the hollow, rotating shaft. Air was forced down the hollow shaft by atmospheric pressure and fine bubbles entered the turbulent water around the impeller. Aerators with less than 2-horsepower motors operated on 110-volt, single-phase power. Larger aerators had 230/460 volt, 3-phase motors.

Aerators ranging in size from 0.125 to 20-horsepower had SAE values of 2.1 to 3.1 pounds of oxygen per horsepower-hour, table 6; and the average SAE was 2.6 pounds of oxygen per horsepower-hour. SOTR increased with aerator horsepower and ranged from 0.26 to 53.9 pounds of oxygen per hour.

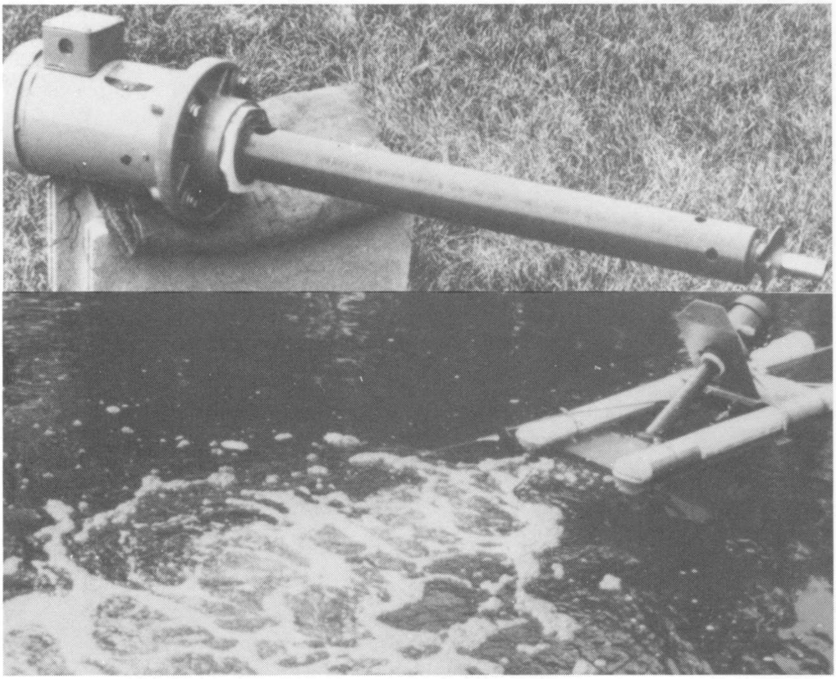

FIG. 30. Aire-O_2 propeller aspirator pump aerators.

TABLE 6. PERFORMANCE DATA ON PROPELLER ASPIRATOR PUMP (AIRE-0_2) AERATORS TESTED

Power at aerator shaft, hp	SOTR[1]	SAE[2]	Operating costs[3]	
			Per hr.	Per lb. 0_2
	Lb. 0_2/hr.	*Lb. 0_2/hp-hr.*	*Dol.*	*Dol.*
0.125	0.26 ± 0.02	2.1	0.009	0.035
0.25	0.65 ± 0.07	2.6	.017	.026
0.5	1.4 ± 0.1	2.8	.035	.025
1.0	2.2 ± 0.2	2.2	.07	.032
2.0	5.6 ± 0.1	2.8	.14	.025
3.0	9.3 ± 0.4	3.1	.21	.023
5.0	11.0 ± 0.7	2.2	.35	.032
7.5	21.8 ± 2.1	2.9	.52	.024
10.0	23.2 ± 1.1	2.3	.70	.030
15.0	45.1 ± 3.1	3.0	1.05	.023
20.0	53.9 ± 2.5	2.7	1.40	.026

[1] Standard oxygen transfer rate.
[2] Standard aeration efficiency; SOTR divided by power applied to aerator shaft.
[3] Based on electricity cost of $0.075 per kilowatt-hour.

Diffuser Aerators

Hinde - Hinde Engineering, Highland Park, Illinois, fabricated this diffuser aerator (no picture available). It consisted of a 0.75-horsepower low pressure blower to force air through tubing that had 0.5-inch-long slits at 18-inch intervals along its top side. A lead filled keel on the bottom of the tubing prevented the tubing from floating. Air was released through four, 29-foot-long lines of tubing at the bottom of the aeration tank. Air flowed into the tubing at 3 square feet per minute and 3 pounds per square inch of pressure. Water depth in the tank was 47 inches.

Values for SOTR and SAE were 1.4 pounds of oxygen per hour and 1.9 pounds of oxygen per horsepower-hour, respectively, table 7.

Microshear - This prototype aeration system was produced by Aeras Water Resources, Eden Prairie, Minnesota. The system, figure 31, was quite complex. It employed an air diffuser nozzle to inject air through an exchange surface into a high velocity stream of water. Converging venturi action reduced water pressure and film forces for

TABLE 7. PERFORMANCE DATA FOR DIFFUSER AERATORS TESTED

Aerator	Power	SOTR[1]	SAE[2]	Operating costs[3]	
				Per hr.	Per lb. 0_2
	hp	*Lb. 0_2/hr.*	*Lb. 0_2/hp-hr.*	*Dol.*	*Dol.*
Hinde	0.75	1.4 ± 0.1	1.9	0.05	0.036
Microshear	1.7	2.4 ± 0.2	1.7	.12	.050

[1] Standard oxygen transfer rate.
[2] Standard aeration efficiency; SOTR divided by power applied to aerator shaft.
[3] Based on electricity cost of $0.075 per kilowatt-hour.

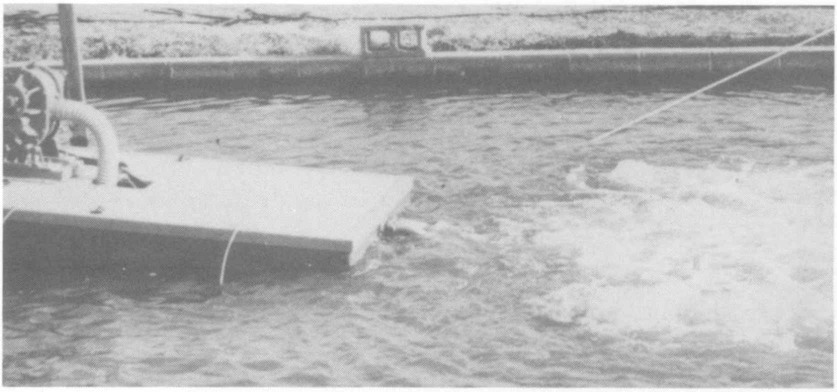

FIG. 31. Microshear diffuser aerator.

bubble formation and permitted air to pass from the injector in the form of a high volume stream of sheared microbubbles. The full-scale system employed a 10-horsepower, 230-volt, 3-phase motor to power the air supply (Roots Universal RA1 Blower, 150 cubic feet per minute) and water supply (Hypro Model 9203C Centrifugal Pump, 125 g.p.m.). The device was mounted on a floating fiberglass platform. Air was injected through six nozzles that were 1 foot apart and about 1.5 feet below the water surface. Oxygen-transfer tests were conducted with a scaled-down model of the aerator that was rated at 1.7 horsepower.

The Microshear unit produced a SOTR of 2.4 pounds of oxygen per hour and a SAE of 1.4 pounds of oxygen per horsepower-hour, table 7. Since these tests were conducted, the Microshear aerator has been modified. Preliminary tests indicate that the new version of the Microshear aerator is much more efficient than the prototype unit described above.

Comparison of Electric Aerators

Data on oxygen transfer (SOTR and SAE), power required at the aerator shaft, power consumption, and operating cost are summarized in tables 3-7. In table 8, SAE values are presented for the different aerator types. The order of increasing efficiency (SAE) follows: diffuser aerators, pump sprayer aerators = vertical pump aerators, propeller aspirator pump aerators, and paddle wheel aerators. Operating cost in dollars per pound of oxygen decreased as efficiency increased, table 8.

Diffuser aerators often are highly efficient in aerating wastewater treatment basins. These basins are 10 to 30 feet deep, so there is a fairly long contact time between rising air bubbles and water (hang

TABLE 8. AVERAGES OF STANDARD AERATION EFFICIENCY (SAE) VALUES AND OPERATING COSTS FOR ELECTRIC AERATORS

Type of aerator	Average SAE	Average operating cost/lb. 0_2
	Lb. 0_2/hp-hr.	*Dol.*
Paddle wheel	3.5	0.024
Propeller aspirator pump	2.6	.027
Vertical pumps	2.1	.036
Pump sprayer	2.1	.036
Diffused air	1.6	.043

time). Fish ponds are seldom more than 5 feet deep, so the hang time for bubbles is much less than in wastewater treatment basins. Therefore, diffuser aerators are less efficient in fish ponds than in wastewater treatment basins, because of insufficient time for absorption of oxygen from the rising bubbles. The tubing of diffuser aerators is easily clogged by sediment and by benthic organisms which encrust the tubing. Furthermore, the tubing obstructs seining operations.

One pump sprayer aerator, the Airmaster, had a high SAE, the other two were inefficient because too much energy was spent in accelerating water. For a pump style aerator, the pump should discharge a high volume of water at low or medium head. At high head, discharge is reduced and oxygen transfer efficiency declines. The sprayer is not essential for aeration with a low or medium head pump, but the sprayer improves water circulation. The Airmaster aerator is especially efficient in circulating pond water (*13*). The Airmaster also is operated by a belt drive without a gear reducer and flexible coupling; hence, it should seldom have mechanical failures.

Vertical pump aerators are appealing because of their simplicity. The impeller usually is connected directly to the motor output shaft, eliminating the need for gear reducers. Propeller speeds of 1,750 and 3,450 r.p.m. have been used, but a 1,750 r.p.m. motor is probably the best choice. Motors can be mounted above or below the water surface. Motors mounted above the water surface are easier to service. For maximum oxygen transfer efficiency, the aerator should pump as much water into the air as possible for the rated pump horsepower. Therefore, impeller selection is critical. The height of the water jet is not critical, the pumping rate is much more important. White water (shearing of water) must be produced if a vertical pump aerator is to transfer appreciable oxygen, but once shearing is produced, as much water as possible should be pumped through the shear zone. Formation of a high jet of water wastes energy that could be used more efficiently for pumping. The cone-shaped diffuser on some aerators is useful in developing a nice water discharge pattern.

Because diffusers are inexpensive, their use is desirable. A number of companies manufacture vertical pump aerators for use in waste water treatment. These aerators typically have SAE rates of 2.5 to 3.5 pounds of oxygen per horsepower-hour (*15*). Unfortunately, they usually are too expensive for use in fish farming.

Small vertical pump aerators are particularly useful for aerating fish ponds of 0.1 to 2 acres which are common on fish hatcheries and research stations. The Power House and Air-o-later aerators are small enough and sufficiently efficient for this task.

Propeller aspirator pump aerators (Aire-0_2) have good oxygen-transfer efficiencies and excellent water circulation capabilities (*6*). They are of rugged construction and have low service requirements. Aire-0_2 aerators have been improved by several years of research and development, and the authors can offer no suggestions for improving their performance. This Air-0_2 is available in a variety of sizes, and it should have a wide range of applications in fish culture.

Paddle wheel aerators tested in this study covered a wide range of SAE values (1.9 to 4.9 pounds of oxygen per horsepower-hour). Paddle wheel aerators specified as House, Geddie, Martar, and S and N, table 3, were similar in design to the optimum design features for paddle wheel aerators described by Boyd and Ahmad in an unpublished manuscript. These paddle wheel aerators clearly were superior to all other aerators. The aerator produced by Dan's Mechanics, table 3, would be more efficient if the paddle wheel was turned slower and the paddle depth increased. The Beaver Tail aerator had an excessive paddle wheel speed; and the short paddle wheels employed on this aerator lead also to inefficiency. The Fritz paddle wheel aerator was not highly efficient, but it would be suitable for aerating 1- to 2-acre ponds. Aerators designated Rogers and Spree were built by fish farmers for their own use rather than as commercial ventures. Although inefficient, these aerators transfer enough oxygen to be useful.

The AMECO PVC paddle wheel aerator was unique. The PVC and fiberglass construction was lightweight, sturdy, and resistant to corrosion. Unfortunately, extensive research on variations in design and operating conditions for PVC paddle wheels (Boyd, Ahmad, and Lafa, unpublished manuscript) suggested that it was not possible to build a PVC paddle wheel that was as efficient as a steel paddle wheel.

Electric Paddle Wheel Aerator Design

Results of aeration tests suggest that 10- or 12-foot-long paddle wheels with paddles of triangular or polygonal cross section and a total diameter of about 36 inches is a good design. The paddle wheel speed should be 80 to 90 r.p.m. with a paddle depth sufficient to load the motor. Once the speed is selected, the optimum paddle depth can be determined as the depth necessary to draw the rated amperes of the motor.

To prolong the service life of the motor, it should only draw 90 percent of its full-load amperes rating. Even though most electric motors have a service factor of 1.10 or 1.15, they will last longer if they are not fully loaded.

Shafts of most electric motors used for paddle wheel aerators rotate at 1,750 r.p.m., so some method must be used to reduce the motor speed to the desired aerator shaft speed. Some aerators described above had gearmotors. In a gearmotor, the gear reducer is built onto the motor and the motor output shaft rotates at the desired aerator shaft speed. For other aerators, a separate gear reducer was employed, and a belt drive was used to connect the motor and gear reducer. Also, a flexible coupling should connect the gearmotor or gear reducer output shaft to the aerator shaft. Gearmotors or separate gear reducers are both suitable means of obtaining the desired aerator shaft speed. However, both techniques are expensive.

An alternative method of motor speed reduction is to mount a jackshaft on the aerator frame and connect the motor shaft to the jackshaft with a belt. Double or triple cog belt drives are best. By selecting a large pulley for the jackshaft and a small pulley for the motor, the jackshaft speed will be much slower than the motor output shaft speed. The aerator shaft can be driven by the jackshaft with a roller chain. A small sprocket can be mounted on the jackshaft and a large sprocket on the aerator shaft to obtain the desired aerator shaft speed. For example, an aerator shaft speed of 90 r.p.m. may be obtained as follows: 4-inch-diameter pulley on motor, 18.5-inch pulley on jackshaft, 16-tooth sprocket on jackshaft, and 70-tooth sprocket on aerator shaft. A thin metal cover over the drive assembly will protect belts, roller chain, and bearings from water. The jackshaft means of achieving the desired aerator shaft speed is less expensive than other methods, because it eliminates the need for a gear reducer (or gearmotor) and flexible coupling.

Most electric paddle wheel aerators are mounted on floats, but some fish farmers have used electric motors to power trailer-mounted paddle wheel aerators. Such paddle wheel aerators look like a tractor-powered paddle wheel aerator, but an electric motor is mounted on the trailer and connected to the aerator drive shaft through belts and pulleys. This eliminates the necessity of a tractor to power each aerator.

Another variation in paddle wheel aerators is shown in figure 32. This aerator was fabricated by researchers at the Delta Branch Experiment Station, Mississippi Agricultural and Forestry Experiment Station, Stoneville, Mississippi. The paddle wheel was mounted on floats, but the motor and jackshafts for speed reduction were anchored on the pond bank. The paddle wheel was driven by a long shaft which was connected by universal joints to the jackshaft and the aerator shaft. This is an excellent design; the motor, electrical connections, and speed reduction mechanism are easy to service, and they can be better protected from splashing water.

Further research may provide some additional improvements in paddle wheel aerator performance, but drastic improvements are not expected. Efforts to develop better floatation devices and more suit-

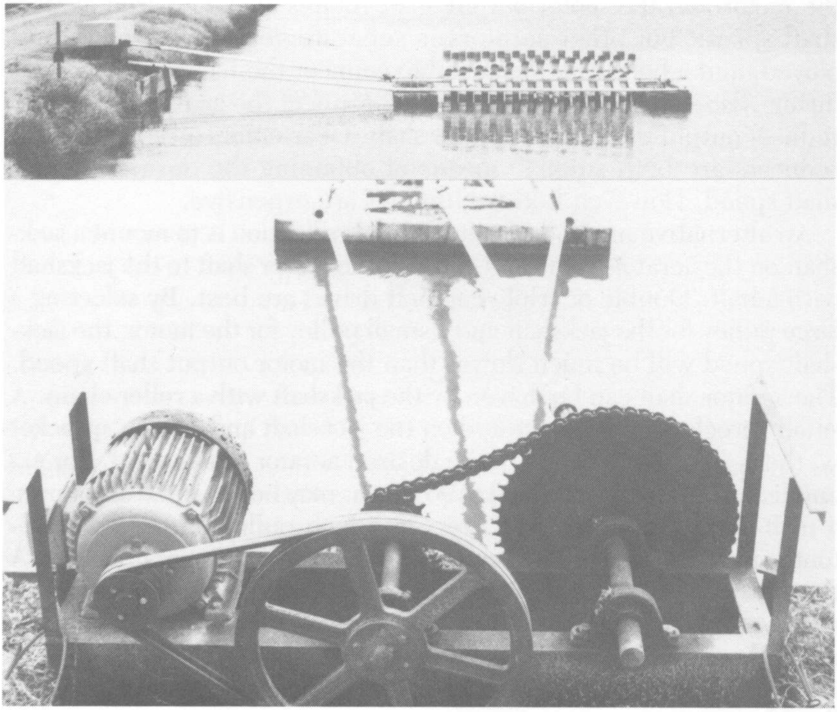

FIG. 32. Paddle wheel aerator with motor and speed reduction assembly on pond bank.

able methods for anchoring and stabilizing paddle wheel aerators could be fruitful. Paddle wheel aerators can create turbidity in ponds, and research on techniques for reducing the potential of paddle wheel aerators to create turbidity is needed.

SUMMARY

Emergency aerators powered by tractors (65 horsepower or larger) had standard oxygen transfer rates (SOTR) of 17.3 to 162.8 pounds of oxygen per hour. Standard aeration efficiencies (SAE) were not determined for tractor-powered aerators. Several of the emergency aerators were well suited for use in channel catfish farming.

Electric aerators (0.33 to 20 horsepower) included paddle wheel aerators, propeller aspirator pump aerators, vertical pump aerators, pump sprayer aerators, and diffused air aerators. Paddle wheel aerators generally were more efficient in transferring oxygen than other types of electric aerators. The best 10-horsepower electric paddle wheel aerators had SOTR values of 38.3 to 51.3 pounds of oxygen per hour and SAE values greater than 4.0 pounds of oxygen per horsepower-hour. Hence, these aerators transferred almost as much oxygen per hour as tractor-powered aerators which required much more energy. Other types of electric aerators had SAE values of 3.2 pounds of oxygen per acre or less, but propeller aspirator pump aerators, one pump sprayer aerator, and some vertical pump aerators were efficient enough for use in fish farming.

Aeration efficiency is not the only consideration in selecting aerators. Some fish farmers prefer an aerator that produces strong water currents, and aeration efficiency must be sacrificed to some extent to obtain maximum water circulation. Other factors are initial cost, durability, availability of parts, and service provided by supplier. Many of the aerators described above can be used effectively in fish farming, and one cannot identify one aerator as clearly being superior to all others. As with any piece of equipment, facts must be considered, but the prospective buyer must ultimately decide which aerator he prefers.

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