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The Effect of Paddlewheel Aerators on Ammonia and Carbon Dioxide Removal in Intensive Pond Culture*

LEAH MAY B. VER
YVONNE N. CHIU
Brackishwater Aquaculture Center
College of Fisheries
University of the Philippines
in the Visayas
Leganes, Iloilo
Philippines

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Abstract

In intensive pond fish culture, good water quality is critical for fish growth and survival. Various water management techniques have been developed to maintain adequate levels of dissolved oxygen and to prevent the accumulation of ammonia and carbon dioxide to toxic levels. This study investigated the effect of paddlewheel aerators on the removal of ammonia and carbon dioxide and to ascertain its well-established effect of maintaining optimum dissolved oxygen levels in ponds sustaining a high biomass. A 500-m^2 earthen pond was stocked with *Oreochromis niloticus* averaging 170 g each to attain a total biomass of 3,000 kg/ha. Un-ionized ammonia and carbon dioxide levels were monitored every four hours for both aerated and unaerated conditions in the same pond. Each treatment was monitored over 24-hour cycles. Results indicate a significant effect of aeration on the diel pattern for carbon dioxide but none on ammonia. Carbon dioxide levels accumulated through the night and peaked between 4 and 8 a.m. at which time aeration significantly reduced it. Ammonia concentration was highest at 4 p.m. regardless of treatment.

Introduction

In intensive pond fish culture, good water quality is critical for fish survival and growth. The high biomass sustained in the pond, coupled with fertilization and feeding can result in the accumulation of toxic metabolites such as un-ionized ammonia and carbon dioxide excreted as metabolic end-products of fish, other organisms and microorganisms.

Ammonia exists in pond water in two forms: un-ionized (NH_3) and ionized (NH_4^+). Its toxic effects are mainly associated with the un-ionized form, the concentration of which is related to total ammonia content, water pH and temperature (Eddy 1982). Carbon dioxide (CO_2) dissolves in water to form carbonic acid (H_2CO_3) which dissociates into bicarbonate (HCO_3^-) and hydrogen (H^+) ions. The HCO_3^- in turn dissociates further to form carbonate ($CO_3^=$) ions and more H^+. Carbon dioxide is relatively more toxic than the other forms, and high concentration can result in a significant decrease in pond water pH. The relative proportions of NH_3 and NH_4^+ and of CO_2, H_2CO_3 HCO_3^- and $CO_3^=$ are dependent on pH and temperature.

Water surface agitation exposes a larger portion of the water to the atmosphere. When a concentration gradient exists across the air-water interface, mass transfer occurs down the gradient to bring the atmospheric and dissolved gas concentrations into equilibrium. Since both NH_3 and CO_2 are in dissolved gaseous forms in the pond, it is possible that water surface agitation will effect their volatilization when gaseous concentrations are higher than atmospheric concentrations.

The paddlewheel aerator has long been established as a very effective device for adding dissolved oxygen (DO) to oxygen-depleted pond water (Boyd and Tucker 1979). Originally conceived as an emergency aeration device for use only during periods of low DO levels, such as the early morning hours or after massive phytoplankton die-offs, many fish farmers now operate it continuously throughout the day to remove toxic gaseous elements and maintain optimum levels of DO.

The results are to form the basis for the development of an improved water-quality management strategy for intensive pond culture with the use of paddlewheel aerators.

Materials and Methods

The experiment was conducted in a 500-m^2 earthen pond with an average water depth of 0.75 m. *Oreochromis niloticus* averaging 170 g each, total biomass 3,000 kg/ha, were stocked and fed a commercial diet containing 35% protein thrice daily at a rate of 2% body weight.

An aerator with two 60-cm paddlewheels was installed in the northern corner of the pond. The paddlewheels, powered by a 0.5-hp electric motor, rotated at about 138 rpm. Leaks in the aerator float were effectively monitored by periodic measurements of the current being drawn by the motor. A draw of 2-3 amperes was considered optimum.

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Water temperature, pH, salinity, water depth, dissolved oxygen, un-ionized ammonia and carbon dioxide concentrations were monitored every four hours in two 24-hour cycles each for the aerated and unaerated conditions. Parameters for the two treatments were measured and the effects of aeration monitored. Weather conditions and the response of the fish were also noted. Water samples for pH, NH_3 and CO_2 determinations were drawn near the surface and bottom at three points in the pond: eastern and western and center. Temperature and DO were measured in the laboratory with a Corning pH meter Model 10. Total ammonia-nitrogen and CO_2 (alkalinity) were determined according to the methods described by Strickland and Parsons (1972) and APHA (1975), respectively. Un-ionized NH_3 concentrations were calculated using data from Emerson et al. (1975). A pH meter was used to determine alkalinity at the equivalence point at pH 4.5 as no sharp color change was observed at the methyl orange endpoint. Alkalinity values were then converted to total carbon dioxide levels according to Strickland and Parsons (1972).

The data were subjected to an analysis of variance to determine whether significant changes occurred at different periods over a 24-hour cycle and to compare the effect of paddlewheel aeration on NH_3 and CO_2 levels.

Results

Results are based on data collected over four continuous days of observation. Water salinity ranged from 34-35 ppt. Pond water was rather turbid, the pond bottom not visible even on sunny days. Water temperature was 24.5-30.8°C under aerated conditions and 26.5-31.4°C under unaerated conditions. Table 1 compares water quality parameter values between aerated and unaerated pond conditions. Figs. 1-4 compare DO, pH, CO_2 and NH_3 levels between the two conditions.

Carbon dioxide concentrations were significantly affected ($P < 0.05$) by aeration. Carbon dioxide levels peaked at around 4 a.m. until aeration significantly reduced it. At this time, the mean CO_2 level under aerated conditions was 3.98 mmoles/l compared to 4.36 mmoles/l under unaerated conditions. At a mean 24-hour concentration of 2.83 mmoles/l in this high biomass pond under unaerated conditions, CO_2 levels were significantly higher than the average of 0.50 mmoles/l in an adjacent pond sustaining a biomass one magnitude lower.

There were no significant differences ($P > 0.05$) in NH_3 concentrations between an aerated and an unaerated pond. Ammonia and pH levels were highest at 4 p.m. and lowest at 4 a.m. regardless of treatment. The average total ammonia concentration of 0.18 mg/l, however, was significantly higher than the average of 0.08 mg/l in the adjacent low biomass pond.

The weather on all four days of observation was fair with moderate wind and sparse clouds. However, between 4 p.m. and 12 midnight on day 4 (unaerated condition), the wind stopped blowing. This sudden change in weather may have been the cause of the plunge of pH and DO levels to a critical low of 6.88 and 2.88 mg/l, respectively at 12 midnight. Some fish were observed to be at or near the water surface while a few were observed leaping out of the water.

Discussion

The results clearly demonstrate the significant increase in pond carbon dioxide and total ammonia levels and depletion of DO to limiting levels due to crowding of fish. Low pH, high CO_2, ammonia, nitrite and low oxygen are all deleterious to fish health, impair growth, and result in a variety of other sublethal effects (Randall et al. 1982). Un-ionized ammonia can readily diffuse across gill membranes with its lipid solubility and lack of charge (Randall et al. 1982) and sublethal concentrations may reduce growth, damage dorsal fins, pectoral fins and other organs, cause gill hyperplasia, thickening of the gill epithelieum, fusion of lamellae, swollen gills and hemorrhaging and predispose fish to disease (Colt and Tchobanoglous 1978; Redner and Stickney 1979; Randall et al. 1982; Soderberg et al. 1983). Hypercapnia, a condition resulting from an increase in ambient CO_2, typically causes a rapid decrease in blood pH due to elevated arterial partial pressure of CO_2 in fish (Randall et al. 1982).

Significant changes in diel pattern of pH, CO_2, NH_3 and DO were observed in the pond with high stocking density. The pattern follows that which results from photosynthesis of pond flora and respiration of the fish and other organisms. With sunlight, photosynthesis brings about an increase in DO to a late afternoon maximum and a reduction in the concentration of dissolved CO_2 to a late afternoon minimum. During the dark, continuing respiration results in diminishing DO and accumulation of CO_2 with their respective minimum and maximum occurring around dawn. Changes in pH correlated negatively with CO_2 concentrations, indicating that the buffering capacity of the pond saline water was not adequate to prevent pH fluctuations of 6.88-8.11. Changes in pH altered the relative concentration of un-ionized NH_3. At equilibrium, the ratio of NH_3 to total NH_3-NH_4^+ will increase as pH increases and decrease as pH decreases. The resulting peak NH_3 level at 4 p.m., corresponding with the peak water pH is consistent with this condition. At a particular pH, the concentration of

ammonia also correlates positively with temperature since the equilibrium constant, K, for the system, increases with temperature.

The ranges of pH, DO and CO_2 concentrations were wider and the peaks more pronounced without aeration. These results indicate the positive effect of aerators on the maintenance of optimum DO levels and on the removal of CO_2 from the pond water. Maximum removal occurs at 8 a.m. when CO_2 levels are high, DO levels are low and photosynthesis is not yet significant. Removal of CO_2 by aeration at this time is particularly significant because the most detrimental effect of CO_2 in fish culture occurs at high CO_2 and low DO levels (Boyd 1979).

Ammonia was not significantly removed by the paddlewheel aerators even at its peak levels at 4 p.m. NH_3 loss rates due to volatilization increased with increasing wind speed, temperature and pH, with significant volatilization at pH 9 (Weiler 1979). In this study, the maximum pH observed was only 8.11. It is possible that volatilization was not observed, as the ionized and un-ionized forms of ammonia were near equilibrium and their relative levels were mainly determined by temperature and pH. Variations in total ammonia levels may have resulted mainly from respiration, photosynthesis and nitrification.

The sudden cessation of the wind between 4 p.m. and 12 midnight on day 4 (unaerated condition) caused CO_2 levels to rapidly accumulate by as much as 3.27 mmoles/l. Un-ionized NH_3 levels dropped by 0.015 mg/l due mainly to the rapid decline in pH. This isolated occurrence underscores the effect of water surface agitation on the removal of carbon dioxide and further supports the other data gathered during the rest of the experiment. Water quality parameter values returned to normal after wind speed increased at midnight.

It is thus recommended that paddlewheel aerators be operated not only during periods of low DO levels but also when CO_2 levels are expected to accumulate to toxic levels, such as in the early morning hours, after massive phytoplankton die-offs, or when air is still. In addition to aeration, regular partial change of the pond water (flushing) to reduce the levels of toxic substances is recommended, as aeration cannot adequately remove metabolic wastes.

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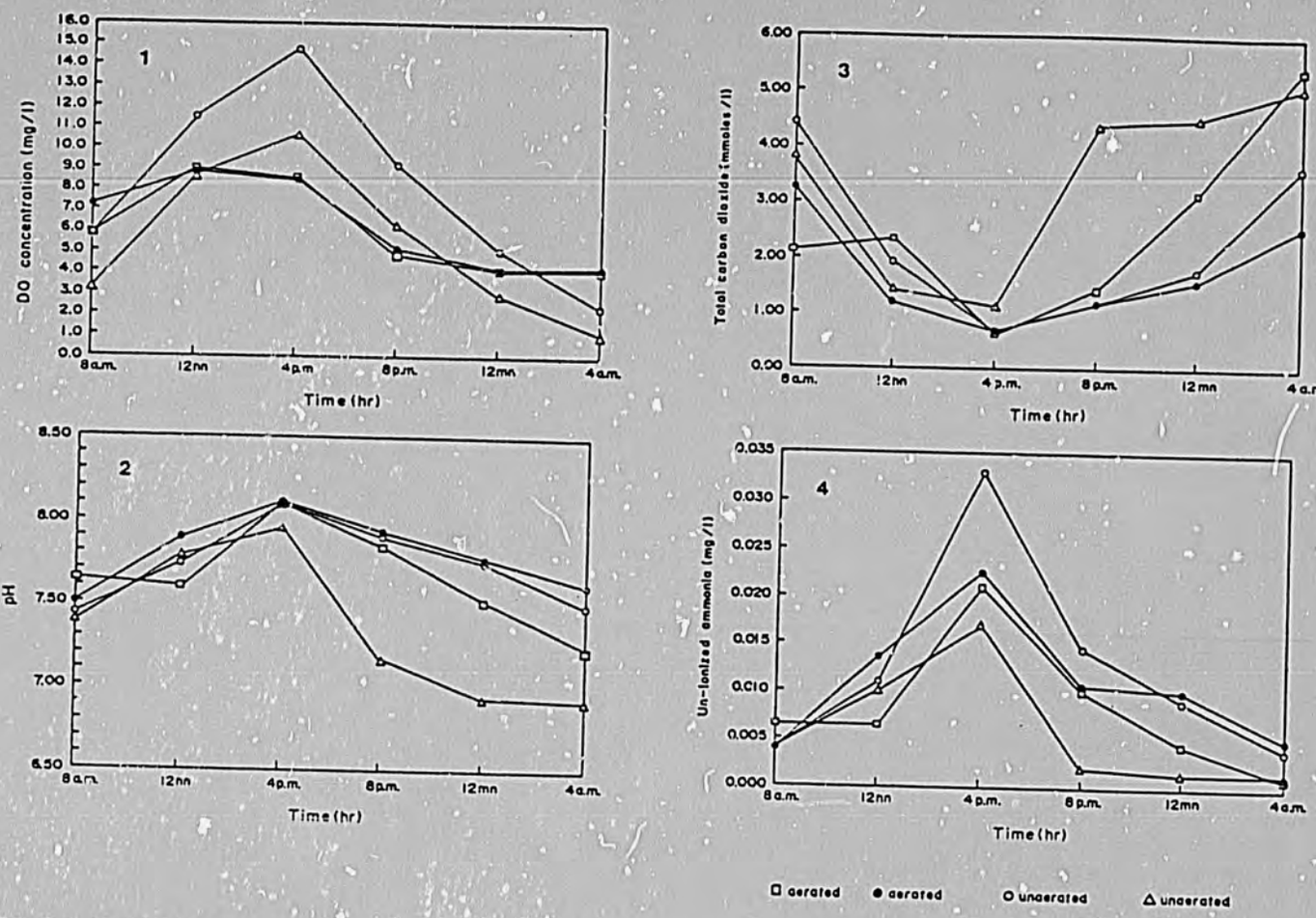
Table 1. Water quality parameter values in aerated and unaerated ponds at 34-35 ppt.

Parameter	Aerated (24.5-30.8°C)		Unaerated (25.5-31.4°C)	
Min DO mg/l	4.1	12 midnight	1.1	4 a.m.
Max DO mg/l	3.0	12 a.m.	14.7	4 p.m.
Min pH	7.24	4 a.m.	6.88	12 midnight
Max pH	8.11	4 p.m.	8.09	4 p.m.
Min NH_3 mg/l	0.001	4 a.m.	0.002	4 a.m.
Max NH_3 mg/l	0.023	4 p.m.	0.033	4 p.m.
Min CO_2 mmoles/l	0.63	4 p.m.	0.68	4 p.m.
Max CO_2 mmoles/l	5.43	4 a.m.	5.09	4 a.m.



Figs. 1-4. Dissolved oxygen concentration, pH levels, and carbon dioxide and un-ionized ammonia concentrations, respectively, in the experimental pond over 20 hours. Two cycles for each parameter.

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