Automated maintenance of dissolved oxygen concentrations in flow-through aquaria

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ABSTRACT


An electronically controlled system is described which reduces variation in oxygen concentration and maintains preset levels of oxygen in a flow-through aquarium unit. Oxygen concentration varies minimally over time and among ten replicate aquaria (2.2\% for normoxic; 3.5\% for hypoxic; 5.7\% for low hypoxic). The advantages of this system are that it is simple, the oxygen concentration does not fall below the preset oxygen value, it can be adjusted to allow for different flow-through regimes, and its automatic design allows accurate repeatability.

INTRODUCTION

This report describes an improved system to regulate dissolved oxygen concentrations in flow-through experimental aquaria using nitrogen gas displacement. This system is simpler to construct than that described by Bevan and Kramer (1988, the BK system) but still provides the recirculating nitrogen feedback loop to reduce nitrogen costs. The system supports ten replicate aquaria (21 l each) per oxygen-controlling unit and is limited only by the volume of water that the external standpipe can remove from the aquaria.

MATERIALS AND METHODS

The system was designed to provide hypoxic water (various levels) to a number of replicate experimental aquaria simultaneously while maintaining a flow-through system. The basic system is similar to the BK system but the modifications removed the oxygen electrode loop and associated components, the pressure vent and the semimechanical analog-to-digital convertor.
(Fig. 1A). The removal of the latter component avoids the falling dissolved oxygen concentration noted in the BK system. Dechlorinated tap water enters the deoxygenation tank (209 l) via a flow meter. Nitrogen gas is bubbled through a large airstone into the tank which is covered by a polyethylene lid. The resulting nitrogen/air mixture is circulated to a sealed chamber (submerged in a water jacket) enclosing a small air pump which returns the gas mixture to the tank. A separate pressure vent is not used (as in the BK system) but a tube is simply connected to the sealed air-pump chamber and placed into the water jacket of the air-pump chamber. The oxygen probe (YSI Model 54 with AC current adapter) is placed “in-line” and measures the dissolved oxygen concentration flowing by gravity out of the deoxygenation tank. This modification reduces the cost of purchasing, drilling and tapping the plexiglass block for the oxygen electrode and the water pump used to circulate water from the deoxygenation tank to the oxygen electrode, as in the BK system. Additionally, an “in-line” bubble trap is placed upstream of the oxygen probe and is used to capture any air bubbles in the outflow lines. Deoxygenated water flows to a PVC manifold that feeds replicate aquaria via airline tubing and screw clamps. The amount of water added to the aquaria is regulated manually when the system is initially set up and is limited by the amount of water the external standpipe can remove.

Nitrogen is regulated by a solenoid valve and coil (Granger solenoid valve #1A575 and a 6×543 coil) connected to the pressure gauge and oxygen me-

Fig. 1. Schematic of (A) entire oxygen stripping system and (B) external stand-pipe. SC=solenoid and coil; EC=electronic controller; P=air pump.
ter via the electronic controller (Fig. 1a). The electronic controller continuously monitors the dissolved oxygen level via the 0 to 120 mv (0 to full scale) recorder output of the oxygen level via the 0 to 120 mv (0 to full scale) recorder output of the oxygen meter. By dialing in a number on the calibrated knob the volume of dissolved oxygen is regulated to any value that the YSI meter is capable of measuring.

Controller hardware consists of power supplies and an amplifier section with associated input, output, control and monitoring circuitry, all housed in an aluminum minibox (Fig. 2). Positive and negative 12 v DC power is derived from a 25-v, center-tapped transformer via a bridge rectifier and integrated-circuit voltage regulators with the appropriate filter capacitors. These regulated supplies provide power for the main section of the amplifier, while an 18-v DC unregulated supply (derived from the same transformer, rectifier, and filter) provides power for the operation of the relay.

The amplifier circuitry consists of three sections of a quad operational am-

Fig. 2. Schematic of electronic controller. Com = common terminal; K = kohms; M = Mohms; T = potentiometer ten-turn knob; μ = microfarads; v = volts; GDC.5A = fuse model number; MTH5 = fuse model number; R1070 = diode part number; 324 = operational amplifier; CW = clockwise turns; 7812 = positive integrated-circuit voltage regulator; 7912 = negative integrated-circuit voltage regulator; three arrows = light-emitting diode (light indicators); 2N222 = transistor part number.
plifier, two sections of which are configured as voltage followers, thus creating a high impedance input such that the controller will have negligible effect on the incoming signal from the oxygen meter. The third and final section is configured as a differential amplifier to control sensitivity. A capacitive negative feedback loop prevents oscillation of the circuitry near the tripping threshold.

Control is established with a ten-turn calibrated potentiometer coupled to the differential amplifier as a voltage reference via an internal 100-kohm "span adjust" potentiometer. Initially, the "span adjust" should be set at 100 kohm, then adjusted downward until a full-scale meter deflection just trips the controller when the calibrated potentiometer is set at its maximum value. Further adjustment of the "span" potentiometer is then unnecessary. Output from the differential amplifier is used to control a transistor switch which operates the relay which in turn controls a 120-v AC output operating the solenoid(s).

Three light-emitting diodes are used as status indicators for monitoring "power on", "relay activated" and "solenoid power". Two fuses are provided for protection: one for the amplifier section and a second for the solenoid circuitry. Cable connections to the controller consist of a three-conductor power cord providing 120-v AC for the amplifier and solenoid circuitry, a female extension cord end providing controlled power out to the solenoid(s), and a two-conductor shielded cable for signal input from the oxygen meter. The shield of the input cable is connected to the power supply common on the controller end and clipped away at the oxygen meter end. Appropriate connectors for mating with the oxygen meter recorder jacks are then installed on the two input leads. Cost of controller parts is $ 75.00 to $ 80.00 (1991 US prices) and construction time is 12–15 h.

A separate system is used to produce and maintain saturated oxygen conditions and consists of a polyethylene tank (about 415 l) with a styrofoam cover equipped with a water chiller/aerator (Frigid Unit Model D1-33). Water is pumped (Teel pump #2P401) to a manifold which allows water to flow into replicate tanks via airline tubing. Outflow is regulated as stated above for the deoxygenated water.

Each replicate tank has an external PVC standpipe maintaining tank water level. The PVC pipe is 55.5 mm in diameter and the outflowing nipple is about 210 mm from the base. This simple design is illustrated in Fig. 1B.

RESULTS AND DISCUSSION

The described system maintains accurate and stable oxygen concentrations in each flow-through system. Three systems were constructed, each containing 10 replicate aquaria; one saturated (> 8.0 mg/l), one hypoxic (about 5.4 mg/l) and one low hypoxic (about 3.4 mg/l). Oxygen concentration was regulated over a 54-day period (Fig. 3) with the initial 18 days at saturated con-
Dissolved oxygen concentrations (mg/l) over the 54 days of the experiment. Each value is a mean (N=10). Oxygen concentration variation is indicated by the vertical bar at day 31, which is 95% confidence interval. Within each oxygen level, the data were homoscedastic across time based on Cochran’s C test (P≥0.33).

Fig. 3. Dissolved oxygen concentrations (mg/l) over the 54 days of the experiment. Each value is a mean (N=10). Oxygen concentration variation is indicated by the vertical bar at day 31, which is 95% confidence interval. Within each oxygen level, the data were homoscedastic across time based on Cochran’s C test (P≥0.33).

ditions in all three systems. This was followed by 4 days of decreasing the oxygen concentrations to treatment levels in the two hypoxic systems, then by 28 days treatment oxygen concentrations (1 saturated and 2 hypoxic levels) and finally by 6 days of quickly adjusting oxygen concentrations up and down in the two hypoxic systems to determine the response of the system. Dissolved oxygen in the saturated system (Fig. 3) increased slightly after day 21 because the water level in the tank was reduced resulting in increased aeration. Water temperature during the course of the experiment remained constant at 24.0 ± 2.0°C in all aquaria.

Oxygen concentration at all three levels varied little across time or among replicates and responded within 1–2 days after adjusting the electronic controller up or down (Fig. 3). This stability in oxygen control is not atypical for other designs (Cochran and Babcock, 1974) but our system does it automatically, conserves nitrogen and is repeatable. The cost of nitrogen (at 1991 prices) depends on the desired “realized” oxygen concentration but was US$ 20.00 per 7 days for the hypoxic system (about 5.5 mg/l) and US$ 30.00 per 7 days for the low-hypoxic system (about 3.4 mg/l).

One problem with this flow-through system is that atmospheric oxygen is taken up by the water as it passes through the experimental aquaria. Thus, it is necessary to determine the relationship between the outflowing hypoxic oxygen reading and the “realized” hypoxic reading in the experimental aquaria to obtain a desired “realized” oxygen concentration. In this system there was a significant relationship between the outflow values and the mean “realized” values (N=10) during the experimental period (days 19–47 of Fig. 3) for the low-hypoxic system (r=0.96, P<0.0001), the hypoxic system (r=0.97, P<0.0001) and the saturated system (r=0.58, P<0.01). Regression variables for the trials are tabulated in Table 1. The diffusion of atmospheric ox-
TABLE 1

Regression variables of system outflow oxygen concentrations versus mean “realized” oxygen concentrations between days 19 and 47 in Fig. 3

<table>
<thead>
<tr>
<th>System</th>
<th>Slope</th>
<th>Y-intercept</th>
<th>$r^2$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low hypoxia</td>
<td>1.134</td>
<td>12.499</td>
<td>0.93</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Hypoxia</td>
<td>1.241</td>
<td>7.460</td>
<td>0.94</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Saturated</td>
<td>0.661</td>
<td>27.107</td>
<td>0.34</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

Oxygen into the media can be reduced by placing lids on the experimental aquaria which should effectively reduce exchanges with the atmosphere.

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REFERENCES