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Evaluation of the Absorption Efficiency of the Low Head Oxygenation System

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ABSTRACT

The 'Low Head Oxygenation System' or LHO^{TM} *is a device recently patented for injection of oxygen or other gases into liquids, relying on serial reuse of oxygen through a series of chambers or stages. The device is especially suited for applications where the low hydraulic head limits the use of other oxygen injection devices. The LHO has recently been used to supersaturate water with oxygen for increased production of fish. In this study, the absorption efficiency of the LHO and nitrogen gas supersaturation concentrations were evaluated at five different oxygen gas to liquid ratios (G/L) ranging from 0·10 to 0·83% (0·40–3·20 g* O_2*/min). The mean absorption efficiency of the LHOs ranged from 67·3 to 90·6%, peaking at a G/L of 0·20% (0·79 g* O_2*/min). This oxygen flow corresponded to a mean dissolved oxygen concentration of 12–13 mg/liter entering the raceway. Absorption efficiency decreased as oxygen flows increased. Nitrogen gas saturation was inversely proportional to oxygen flow, and did not fall below 100% saturation until oxygen flows exceeded a G/L of 0·64% (2·50 g/min).*

INTRODUCTION

Oxygen is often the limiting factor in the culture of aquatic organisms (Willoughby, 1968; Liao, 1971; Piper *et al.*, 1986). Therefore to increase production, an increase in the amount of dissolved oxygen (DO) is required in most situations. Many of the hatchery facilities in Utah have a limited amount of hydraulic head, and a demand for greater production of fish (Creer, 1989).

Supersaturation of incoming water by injection of pure oxygen has been achieved recently by using various devices such as the U-tube aerator (Speece & Orosco, 1970), downflow bubble contact aerator (Speece *et al.*, 1971), packed columns (Hackney & Colt, 1982; Watten & Boyd, 1989), and pressurized packed columns (Schutte, 1988; Klar & Parker, 1990). Watten (1989) took the packed column design one step further by connecting several of them side by side. This created a device that reduced the amount of hydraulic head required to oxygenate water, eliminating the need for pumping water and thus reducing the risk of system failure. The device is currently marketed as the 'Low Head Oxygenation System' or LHO™, and is in use at several Utah hatcheries. This project evaluated the oxygen absorption efficiency of the LHO and its effectiveness in reducing nitrogen gas supersaturation at five different oxygen flows.

METHODS

Absorption efficiency and nitrogen gas supersaturation concentrations were evaluated at five different oxygen gas-to-liquid ratios (G/L) ranging from 0·10 to 0·83% (0·40–3·20 g O_2/min). Oxygen flows were determined by measuring the change in weight of the oxygen tank and dividing by the amount of time the tank was supplying oxygen. The length of time for each test varied (372–2498 min), being longer at lower oxygen flows. This maximized the change in weight of the oxygen tank, reducing experimental error in the weight measurement. The precision of the digital scale used was ± 45 g, which would result in only a slight variation (± 1%) in the absorption efficiency. Each mass flow value was converted to a volumetric gas-to-liquid ratio by using the specific volume of oxygen under standard conditions (Colt & Watten, 1988; Dwyer & Peterson, 1993).

Absorption efficiency (AE) was calculated using the formula (Watten & Boyd, 1990),

$$\mathrm{AE} = \frac{Q_\mathrm{L}(DO_\mathrm{out} - DO_\mathrm{i})10^{-3}}{M_{\mathrm{O}_2}}$$

where DO_out is the mean dissolved oxygen of water exiting the eight LHO chambers in mg/liter,

DO_i is the dissolved oxygen of the water entering the LHO,

Q_L is the water flow in liters/min,

10^{-3} is the conversion from mg to g, and

M_{O_2} is the mass flow of oxygen to the unit in g/min.

Gas saturation measurements were made with a saturometer (Sweeney Aquamatic) at the time of the oxygen determinations, with the probe located in the center of the raceway about 1 m downstream of the LHO where the water had mixed sufficiently to get a representative reading. Nitrogen gas saturation values were calculated by a computer program (Cook & Canton, 1988) using barometric pressure readings taken from the saturometer. Temperature (17·2 ± 0·1°C), DO (7·0 ± 0·1 mg/liter), and water flow (291 liters/min) of the hatchery well water were constant during the study. The total gas saturation of the well water was 107·9% (6·78 kPa above the barometric pressure), nitrogen gas saturation was 116·3%, and barometric pressure during the study ranged from 85·0 to 86·2 kPa.

Four raceways 1·22 m wide × 11·58 m long × 0·57 m deep, with commercial LHO units (Zeigler Brothers Inc.), were supplied with oxygen from a single compressed oxygen tank. During the tests, rainbow trout fingerlings, *Oncorhynchus mykiss*, were present in the raceways at densities ranging from 23·4 to 98·0 kg/raceway. The oxygen was delivered to each LHO unit by splitting the flow in half at one manifold and again at another manifold downstream of the first. The manifold fittings were four times larger than the supply line to insure equal amounts of gas to each line. Downstream of the first manifold, a mass-flow controller (Omega Engineering) measured the oxygen flow to the next manifold. Rotameters (Victor, 7 liters/min capacity) were used to control the flow of oxygen to each raceway. Uniform oxygen pressure was controlled in the inflow line by a regulator on the oxygen tank.

The open trough at the top of the LHO (Fig. 1) spread the inflowing water over a horizontal perforated distribution plate. The water jetting through the holes (9-mm diameter) was oxygenated as oxygen flowed perpendicularly through a single hole in each of eight stages or compartments. The oxygen concentration was highest in the first stage and dropped en-route to the last, where the remaining gas was vented. The outlet of the off-gas pipe was kept just below the water surface to provide enough back pressure to maintain a 10-cm depth of water above the distribution plate. The distance from the distribution plate to the water surface of the raceway was 60 cm.

Dissolved oxygen (DO) concentrations were measured with a digital oxygen meter (YSI Inc.) calibrated with replicate Winkler tests (APHA *et al.*, 1989). Oxygen concentrations of water leaving the LHO were made by placing the probe within each stage, on the floor of the raceway. The mechanical stirrer supplied with the oxygen probe was used during each measurement. The meter was given time to equilibrate, then an average

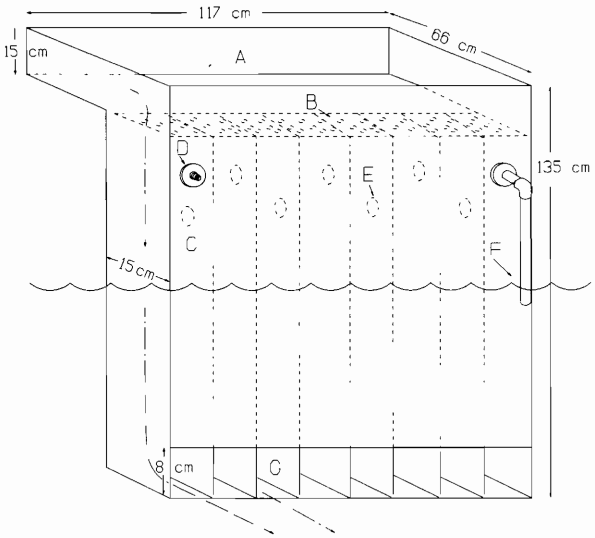

Fig. 1. Diagram of the Low Head Oxygen Injection unit. Water flows into a collection trough (A), through a perforated distribution plate (B), and is oxygenated in the chambers (C) as oxygen flows from the inlet hose barb (D), through the holes between chambers (E), to the off-gas pipe (F) where excess gas is bubbled off underwater. Water exits at the bottom of the unit (G).

of the maximum and minimum DO values observed (nearest hundredth) was recorded (rounding to the nearest tenth). The mean DO of water exiting the eight stages (chambers) of each LHO was used as the DO concentration leaving the LHO. DO of the incoming water was measured in the trough of the LHO. DO readings were taken several times during the testing of each oxygen flow rate to determine if there were any daily fluctuations. No significant fluctuations were observed.

Preliminary tests were conducted from 12 to 18 November 1992 to compare DO concentrations at the tail end of the raceway with the mean DO leaving the LHO. Readings were taken at five different oxygen flow rates in fishless raceways, freshly scrubbed and disinfected with sodium hypochlorite.

RESULTS AND DISCUSSION

The mean absorption efficiency of the LHOs ranged from 67·3 to 90·6%, peaking at a G/L of 0·20% (0·79 g O_2/min), and decreased as oxygen flows increased or decreased from this flow (Fig. 2). For a pressurized

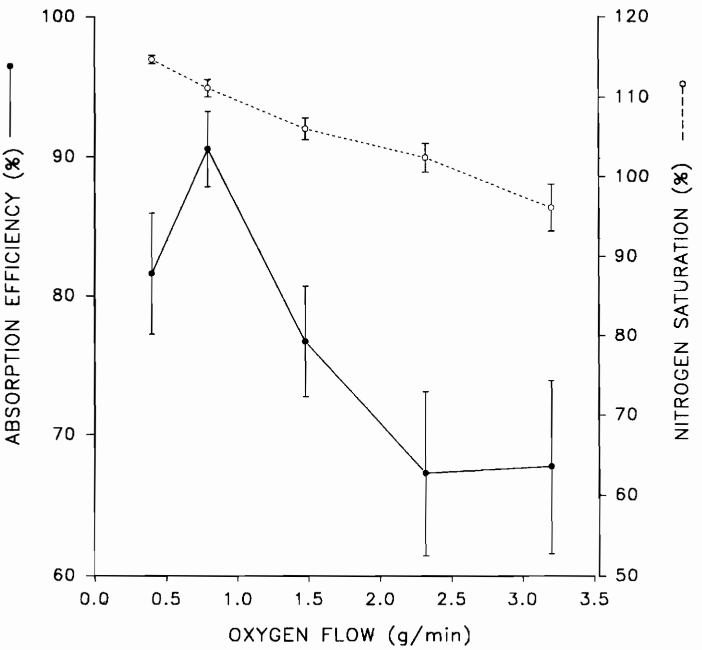

Fig. 2. Mean (± SD) oxygen absorption efficiency and nitrogen gas saturation of three Low Head Oyxgen Injection units at five different oxygen flows.

column, Schutte (1988) reported absorption efficiencies ranging from 32 to 93%, depending upon oxygen flow and chamber pressure. In Shutte's (1988) study, the absorption efficiency increased with the amount of oxygen added at a given pressure. The rate of oxygen flow in that study was lower than the oxygen flow where peak efficiency was noted in this study, corresponding with the increase in absorption efficiency from G/L 0·10 to 0·20% (0·40–0·79 g/min). The absorption efficiency in another study of a pressurized column (Klar & Parker, 1990) peaked at 82·8% at a G/L of 7·7% (2·87 g/min) and a pressure of 5·8 kPa. However, the peak absorption efficiency occurred at lower oxygen flows as the pressure dropped (Klar & Parker, 1990). The pressure of the LHO chambers was controlled by the off-gas pipe depth (hydrostatic pressure), resulting in gauge pressures of 0·20–0·49 kPa. At these low pressures, the peak absorption efficiency of this study and of Klar and Parker's (1990) study occur at similar oxygen flows. The absorption efficiency predicted by Watten and Boyd (1990) for a 10-stage LHO at a G/L of 0·8% was 85%, based on a column height of 0·60 m. At that gas–liquid ratio in this study, the absorption efficiency was 68%. The difference may be related to a number of factors: the number of stages (10 versus 8 in this study), which

TABLE 1

Oxygen Absorption Efficiency (AE) and Gas Saturation Levels (TG = total gas, N = nitrogen) from Four LHO Units under Different Oxygen Flow Rates (G/L = gas-to-liquid ratio). The Dissolved Oxygen Concentration (DO) of the Water Supply was 7·0 ± 0·1 mg/liter

LHO unit	*G/L (%)*	*O_2 Flow (g/min)*	*AE (%)*	*TG (%)*	*N_2 (%)*	*Ratio O_2/N_2*	*Final DO (mg/liter)*
1	0·10	0·40	85·98	109·56	115·13	0·78	8·09
	0·20	0·79	91·70	109·37	110·92	0·94	9·51
	0·38	1·48	72·58	109·53	107·56	1·09	10·75
	0·60	2·32	66·65	110·29	103·69	1·31	12·39
	0·83	3·20	60·63	110·33	99·52	1·53	13·89
2	0·10	0·40	77·28	109·15	114·84	0·77	8·01
	0·20	0·79	87·50	110·24	112·32	0·92	9·42
	0·38	1·48	77·01	108·55	105·74	1·13	10·95
	0·60	2·32	61·75	108·89	103·19	1·27	11·94
	0·83	3·20	71·45	109·17	94·63	1·74	15·06
3[a]	0·10	0·40	59·16	109·50	115·86	0·74	7·81
	0·20	0·79	71·22	109·34	112·47	0·87	8·96
	0·38	1·48	61·63	109·27	108·88	1·02	10·18
	0·60	2·32	56·60	110·21	105·82	1·21	11·62
	0·83	3·20	60·70	109·56	98·64	1·54	13·84
4	0·10	0·40	81·54	108·90	114·17	0·79	8·13
	0·20	0·79	92·53	108·90	110·13	0·95	9·58
	0·38	1·48	80·56	108·45	104·87	1·17	11·20
	0·60	2·32	73·39	109·04	100·34	1·42	12·99
	0·83	3·20	71·17	108·78	94·22	1·74	15·02

[a] Unit 3 featured a deeper trough to the rear of the distribution plate of the LHO.

increase the absorption efficiency (Watten & Boyd, 1990); lower barometric pressures in this study; and cooler temperatures in this study. Oxygen absorption efficiency for LHO units evaluated by Dwyer and Peterson (1993) peaked at 91% at a G/L of 0·12, which was similar to the peak efficiency observed in this study. However, the peak occurred at a slightly higher oxygen flow in this study. Despite the different field conditions and LHO dimensions, the range of absorption efficiencies in Dwyer and Peterson's (1993) study (65·2–91·1%) was similar to the range in this study, where similar G/L ratios were tested.

One of the LHO units in this study was of a different design to that of Fig. 1, differing only in the size of the trough. In this case, the trough was deeper (38 cm) at the back, forming a stilling basin before the water flowed up and over the distribution plate. The absorption efficiency of this LHO was 22% lower than the mean of the other three units at a G/L of 0·10% (0·400 g O_2/min); at higher oxygen flows, this LHO was 7–11% less (Table 1). Since there was only one of these units, no statistical comparison with the other design could be made. However, the data from this LHO were not included in Fig. 2. The reason for the discrepancy is not clear, since the distribution plate, number of stages, width, and height were identical to the other units. Fish density was not a factor since the density of fish in this raceway was identical to that supplied by LHO unit 1 where a peak absorption efficiency of 91·7% was observed.

Nitrogen gas saturation was inversely proportional to oxygen flow, and did not fall below 100% saturation until oxygen flows exceeded a G/L of 0·64% (2·5 g/min; Fig. 2). Nitrogen gas supersaturation can cause gas bubble disease, characterized by lesions in the blood (emboli) or tissues (emphysema; Bouck, 1980). This non-infectious disease may be chronic at low levels of supersaturation, causing pathologies such as blindness (Stroud *et al.*, 1975), or cause significant mortality at high levels of supersaturation (Harvey, 1975). When total gas saturation values are above 100%, higher oxygen-to-nitrogen ratios significantly reduce mortality (Nebeker *et al.*, 1976). Total gas saturation values in this study varied little, ranging only from 108·45 to 110·33 (Table 1).

Measurement of oxygen flows at the tail end of a fishless raceway were similar to measurements derived from the means of the eight stages (Table 2). This was an indication that loss of DO to the atmosphere as it flows down the raceway was negligible and that the baffle mean was an accurate measure of DO leaving the LHO units.

Results of this study indicated that if oxygen flows are high enough, LHO units can be used to successfully increase oxygen concentrations for greater fish production, as well as decreasing the nitrogen gas supersaturation to benign levels. Other oxygen injection devices with absorption efficiencies in the same range include the pressurized packed columns (95–100%), U-tube with off-gas recycling (60–90%) and aeration cones (80–90%; Colt & Watten, 1988). However, the LHO unit is especially applicable in situations where there is limited hydraulic head. As in some of the other oxygen injection methods, the lack of moving parts or the need for pumps also eliminates power costs and reduces maintenance.

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TABLE 2

Comparison of the Mean Dissolved Oxygen (DO) Concentrations Leaving the Low-head Oxygen Injection Unit and DO Leaving the Tail End of a Fishless Raceway at Five Different Oxygen Flows

LHO unit	*LHO DO (mg/liter)*	*Tail DO (mg/liter)*
1	6·7	6·8
	9·2	9·4
	12·0	11·7
	14·1	14·3
	14·9	15·0
2	6·6	6·7
	9·1	9·4
	12·1	12·2
	14·3	14·2
	15·2	15·3
3	6·6	6·7
	9·0	9·2
	12·1	12·0
	14·3	14·4
	15·1	15·0
4	6·8	7·0
	9·0	9·4
	12·4	12·2
	14·2	13·8
	15·0	15·0

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