Dissolved Oxygen Criteria For Fish Culture

By Rob Barratt

Dissolved oxygen is one of the most important water quality parameters for fish culture and is usually the first limiting factor in determining the maximum biomass that a fish culture system can carry.

Dissolved oxygen content can be expressed in three ways:
- mg/l (milligrams per litre, or parts per million), concentration of dissolved oxygen.
- mmHg (millimetres of mercury), partial pressure of dissolved oxygen, or oxygen tension (Po_2),
- % Saturation, a relative value expressing either Po_2 or mg/l of dissolved oxygen as a percentage of their respective air saturation values.

In determining which of these expressions is most appropriate for setting dissolved oxygen criteria, one needs to understand the mechanism by which fish utilize oxygen. Fish take up oxygen by pumping water over the gills, where oxygen diffuses from the water into the blood. The diffusion process depends on the difference in partial pressure, or gradient, between dissolved oxygen in the water and dissolved oxygen in the blood (Po_2 in the water must be greater than Po_2 in the blood). The steeper the partial pressure gradient the greater will be the rate of diffusion.

In air-saturated water (100% sat.) the Po_2 in the water is equal to the partial pressure of oxygen in the air and is determined as follows:

Po_2 = [Barometric Pressure (BP) - Water Vapour Pressure (PH^2O)] x % O_2 in the air

- Standard BP at sea level = 760 mmHg (including PH^2O)
- PH^2O is temperature-dependent. For example, at 10 °C, PH^2O = 9.2 mmHg
- Air contains 20.95% oxygen.

Hence, Po_2 in air-saturated water at 10 °C = (760 mmHg - 9.2 mmHg) x 20.95% = 157.3 mmHg

Po_2 in fish blood varies, but can be assumed to average around 85 mmHg. Hence, for fish in air-saturated water, the partial pressure gradient across which oxygen diffuses is approximately 70 mmHg (157 mmHg - 85 mmHg). A drop in the Po_2 in the water reduces this gradient and depresses the Po_2 in the blood. As water temperature and salinity increase, oxygen concentration decreases due to reduced solubility, but Po_2 remains more or less constant. (Po_2 actually drops slightly as temperature increases due to increasing water vapour pressure.) Thus a fish in warm water must pump more water across the gills than in cold water in order to deliver the same amount of oxygen per unit of time. This is necessary even though the pressure gradient between water and blood is about the same at the higher temperature.

In his paper "Minimal Dissolved Oxygen Requirements of Aquatic Life", John Davis established dissolved oxygen criteria based on "incipient oxygen response thresholds" expressed in terms of Po_2 (mmHg) as well as oxygen concentration (mg/l). The incipient oxygen response threshold is defined as the oxygen level at which fish just start to respond to reduced oxygen availability. In colder water, oxygen response thresholds are dictated by the Po_2 value required for maintaining the necessary pressure gradient for proper gas exchange, whereas in warmer water, where the oxygen concentration is much lower than in colder water with the same Po_2, it is the mg/l value that determines the requirements for respiration. The following table is an excerpt from this paper.

In this table, dissolved oxygen criteria are also given in terms of percent saturation at temperatures ranging from 0 to 25 ∞C. Percent saturation

DISSOLVED OXYGEN CRITERIA DERIVED FROM INCIPIENT DISSOLVED OXYGEN THRESHOLD LEVELS BASED ON Po_2 AND mg/l VALUES

GROUP	Protection Level	Po_2 mmHg	DO Conc. mg/l (1)	% Sat. Criteria derived from mmHg and mg/l values - 0°C to 25°C					
				0°C	5°C	10°C	15°C	20°C	25°C
Mixed fresh water fish population including salmonids	A	110	7.25	69	70	70	71	79	87
	B	85	5.25	54	54	54	54	57	63
	C	60	3.25	38	38	38	38	39	39
Mixed fresh water fish population with no salmonids	A	95	5.50	60	60	60	60	60	66
	B	75	4.00	47	47	47	47	47	48
	C	55	2.50	35	35	35	35	35	36
Fresh water salmonid population (including steelhead)	A	120	7.75	76	76	76	76	85	93
	B	90	6.00	57	57	57	59	65	72
	C	60	4.25	38	38	38	42	46	51
Salmonid larvae and mature salmonid eggs	A	155	9.75	98	98	98	98	100	100
	B	120	8.00	76	76	76	79	87	95
	C	85	6.50	54	54	57	64	71	78
Marine, non anadromous species (2)	A	140	8.75	88	88	95	100	100	100
	B	110	6.75	69	69	74	82	90	98
	C	80	4.50	50	51	51	55	60	65
Anadromous salmonids in sea water (2)	A	160	9.00	100	100	100	100	100	100
	B	125	6.50	79	79	79	79	87	94
	C	90	4.00	57	57	57	57	57	58

NOTE: 1. Oxygen solubility values for fresh water are derived from Whipple 1914 and may differ slightly from values derived from Weiss 1970 as published in "Computation of Dissolved Gas Concentrations in water as functions of Temperature, Salinity and Pressure, Colt J. 1984" now commonly in use.

2. Percent saturation calculations are based on a salinity of 28 ppt

values are derived from either Po_2 or mg/l, whichever value is the determining factor. Higher % saturation values are necessary at higher water temperatures.

From a statistical analysis of the data collected, John Davis devised three levels of protection:

Level A - This represents more or less ideal conditions and assures a high degree of safety for fish stocks.

Level B - This is the oxygen value where the average member of a fish population starts to exhibit symptoms of distress. Some degree of risk exists if the oxygen minimum is prolonged beyond a few hours.

Level C - At this level a large portion of a fish population will be affected and if prolonged beyond a few hours, the deleterious effects can be serious.

In summary, both Po_2 and mg/l are critical for establishing dissolved oxygen criteria. In the fish culture industry, Po_2 is seldom used as an expression for dissolved oxygen. Dissolved oxygen is commonly expressed in mg/l, but this value only has full meaning if the temperature of the water is known. Hence, it is useful to encompass both Po_2 and mg/l in a % saturation value for setting dissolved oxygen criteria, as in the above table.

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Additional reading: Davis, J.C. 1975. Minimal Dissolved Oxygen Requirements of Aquatic Life with Emphasis on Canadian Species: a Review. J. Fish. Res. Board Can. 32: 2295-2332