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Technical Note

Supersaturation and Gas Bubble Disease – Why Measure Total Dissolved Gas?

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When it comes to aquatic organisms and dissolved gases, more is not always better. Gas supersaturation can be harmful to aquatic life of various forms. Levels of supersaturation lethal to aquatic organisms have been found in rivers, estuaries, springs, wells, seawater, ponds, and tanks. Gas supersaturation can be induced in pumped or processed water intended for drinking, fish hatchery supply, and aquaculture. Seasonal and other temporal variations in supersaturation may occur. Because gas re-equilibration may be slow, supersaturation may persist in flowing water for days. Excessive dissolved gases, therefore, can persist far from the source of supersaturation.

Water can become supersaturated with atmospheric gases through various means. Air entrainment in spilled or pumped water and heating are the most common. Supersaturation may also result from the mixing of waters of different temperatures, a decrease in hydrostatic or other confining pressure, or ice formation. The primary sign of gas supersaturation is the formation of bubbles on submerged surfaces or within the vascular systems and tissues of aquatic organisms.

Bubble Formation

Gas bubbles form when the total dissolved gas pressure (the sum of all individual dissolved gas partial pressures, including water vapor pressure) is greater than the compensating pressures. Compensating pressures include hydrostatic and barometric pressures and, for organisms, tissue or blood pressure. Bubble formation and Gas Bubble Disease of fish or other aquatic organisms is a result of excessive uncompensated gas pressure caused by abnormal and unstable physical conditions.

Gas Bubble Disease

Gas Bubble Disease is a condition that affects a wide variety of fish and other aquatic organisms in waters (fresh or saline) supersaturated with atmospheric gases. This condition has been recognized since 1901 when Gorham first described gas bubbles in the tissues of affected fish, including in fins and behind the eyeballs to produce "pop-eye".

Figure 1: "Pop eye." Photo courtesy of The Zebrafish International Resource Center, www.zebrafish.org

Numerous instances of gas bubble disease have been reported in the past century. These include instances of gas supersaturation resulting from air entrained in water supply systems, naturally supersaturated well or spring water, intensive photosynthesis, warming of hatchery of aquaria water supplies, and air entrainment below spillways of major dams. Since the mid-1960's extremely serious mortalities from gas bubble disease have been recognized in the Columbia River System, and a large number of papers have subsequently been published concerning this problem. A special issue of the Transactions of the American Fisheries Society dedicated to Total Dissolved Gas and Gas Bubble Disease was published in November 1980, and this provides recommended reading on the topic.

Symptoms

Gas Bubble Disease can occur in a wide variety of aquatic organisms, although occurrences and symptoms are most thoroughly described for species of economic importance. For juvenile salmonids, the first external sign of gas bubble disease is very small bubbles along the lateral line. The most pertinent symptom to look for is the appearance of bubbles of gas in the gill blood vessels. Two additional symptoms for juvenile salmonids are bubbles or blisters under the skin, particularly in the fin rays, as well as noticeable abnormal behaviors. Adult salmonids can show similar symptoms and frequently develop gas blisters in the roof of the mouth. Salmon fry develop bubbles in the yolk sac and between the yolk sac and the perivitelline membrane. These bubbles often result in noticeable erratic swimming. Salmon eggs generally appear quite tolerant of gas supersaturation.

Acute mortality results when gas bubbles are present in the heart in sufficient quantity to prevent movement of blood. Various sublethal effects have also been reported to significantly impact mortality, most importantly blindness, decreased tolerance to stress, loss of lateral sense, and secondary infections. Acute affects may be reversed by exposure to equilibrated water or to increased hydrostatic pressure. However, permanent affects to individuals and large-scale mortality in populations may occur after only short-term exposure, especially in aquaculture settings and other artificial environments where compensating pressures do not exist. In these settings, large-scale mortality and huge economic losses can occur in a matter of hours.

Species, life-stage, size and genetics are all important factors in determining the tolerance of fish to supersaturated waters. In this regard, the most extensive research has been conducted on salmonids. As a rule-of-thumb, eggs and newly hatched alevins seem most tolerant. Advanced yolk sac, newly buttoned up, and swim-up stages seem to be least tolerant of waters supersaturated with atmospheric gases. Fingerlings are more tolerant, and yearlings and adults still more tolerant. Steelhead have been reported to be the least tolerant of salmonids.

Nitrogen and oxygen are the two most prevalent atmospheric gases. While elevated levels of either of these gases MAY drive waters to overall gas supersaturation, it must be stressed here that measuring just the concentration of oxygen, nitrogen, any other individual gas, or a combination of individual gases will not yield useful information related to this problem. The *total* pressure of all dissolved gasses combined (including water vapor pressure) is the single factor that determines whether bubbles form or not. Measuring dissolved oxygen individually is certainly an important factor in water quality monitoring, but dissolved oxygen readings cannot be used to derive any information about overall gas saturation levels and whether or not Gas Bubble Disease will occur. It is interesting that for two supersaturated waters having identical Total Dissolved Gas levels, the one with higher levels of oxygen will generally have a somewhat lesser effect on fish. This is presumably because oxygen can be removed from tissues via metabolic activity whereas nitrogen cannot. This, however, is of minor importance compared to the overall negative impacts of Total Dissolved Gas supersaturation.

Safe Level Limits

Safe limit recommendations are generally considered separately for natural environments versus captive environments. In natural settings, behavior and hydrostatic pressure can potentially reduce exposure through horizontal and vertical movements of individuals away from dangers. In captive environments such as hatcheries, aquaculture operations, aquaria, or laboratories, conditions not only preclude escape but also include other significant stresses. Of these two realms, captive circumstances are more likely to cause illness or mortality from Gas Bubble Disease and will do so sooner and at lower total gas pressures.

In natural circumstances, the limit of safe gas supersaturation levels depends on the escape depth available and species behavior, but this limit usually occurs between 105% and 120% of equilibrium total gas saturation pressure (ambient atmospheric pressure). Under captive conditions, the total dissolved gas pressure should be as close to 100% as possible. For sensitive species and life stages, sublethal and lethal effects of Gas Bubble Disease have been observed at total dissolved gas pressures as low as 101%.

For this reason, the monitoring of Total Dissolved Gas is a critical component in the management of fresh water, marine, and estuary fisheries as well as the artificial environments of hatcheries, aquaculture, aquariums, and live fish transport. Total Dissolved Gas monitoring is now a fundamental component in the proper management of hydroelectric power generation facilities for the protection of aquatic life.

Figure 2: Gas in yolk sac. Photo courtesy of U.S. Army Corps of Engineers®.

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