DEL ozone™
advanced sanitation solutions

3580 Sueldo Street, San Luis Obispo, California 93401
Phone 800.676.1335 | Fax 805.541.8459

Understanding Ozone Manufactured from Oxygen vs. Dried Air

Beth Hamil, Vice President Corporate Compliance, DEL Ozone
May 5, 2011

Introduction
For many good reasons, ozone has emerged as the preferred foundation for the disinfection of water in aquariums, zoos and human aquatic venues. However, there are different engineering and technical approaches to the design of ozone disinfection systems, and these variations can make important differences for fish, animals, and people using aquatic environments.

One design difference critical for aquariums and other aquatic environments is the choice of oxygen versus dried air as the feed gas for the ozone generators. Until recently, engineers and researchers had a consensus that oxygen was superior to dried air for many reasons (some of which will be reviewed below). In fact the major technology improvement of all commercial ozone generators between 1910 and 1980 was improvement in feed gas preparation, culminating with oxygen concentration technologies. Now, however, some may argue that dried air may produce superior outcomes, especially for commercial aquariums.

There are two major reasons why oxygen is a superior feed gas for aquariums:

1. The oxygen concentrator method of feed gas preparation removes almost all the nitrogen from the feed gas. Since dissolved nitrogen in excess concentrations can pose a threat to fish (nitrogen narcosis), the ozone disinfection system should avoid injecting it into the water.
2. Oxygen feed gas permits a much more efficient ozone system. Generally, an ozone generator using oxygen feed gas will produce twice as much ozone as the same-sized generator using dried air.

In this brief paper we show why oxygen is the better feed gas choice for the disinfection of commercial aquariums, especially for the health of the fish and animals that inhabit them. In comparing ozone to dried air on many performance dimensions, oxygen has significant advantages.

Overview
All commercial ozone systems require high quality feed gas to operate effectively, meaning a gas cleaned of hydrocarbons, particulates and, especially, water vapor. In a corona discharge ozone generator, water vapor reacts with nitrogen in air to create corrosive nitric acid which can destroy the ozonator. Therefore, these systems use dried air, bottled oxygen or oxygen generated on-site (with an oxygen concentrator) in order to achieve a low dew point in the feed gas.

A dried air process (utilizing a desiccant) was originally used in the world's first municipal drinking water ozone sanitation system in 1906. These first air dryers were very inefficient (a dew point of no lower than -4˚ F), and were the cause of about 90% of the maintenance on early ozone systems. Over the decades, improvements were made, such as the invention of pressure swing adsorption (PSA) air dryers in the early 1940s. However,

3580 Sueldo Street, San Luis Obispo, California 93401
Phone 800.676.1335 | Fax 805.541.8459

dried air has remained a relatively inefficient approach (even though it reduces water content) because it delivers a feed gas with roughly the same composition as air (that is, about 21% oxygen), limiting the ozone delivery efficiency of the system.

In about 1958, a major advance occurred with the invention of PSA oxygen concentrators. Oxygen concentrators are capable of removing virtually all water vapor from ambient air to produce a very clean feed gas that yields a highly cost-effective ozone system. Perhaps equally important for aquariums, oxygen concentrators produce an oxygen-enriched feed gas that contains almost no nitrogen, thereby eliminating the danger of nitrogen narcosis. At the same time, the concentration of dissolved oxygen can be managed easily, producing an optimal environment.

Since the early 1990s, oxygen (preferably from oxygen concentrators offering a dew point of -100° F) has been the preferred method for modern ozone systems, especially for commercial aquariums.

A Technical Comparison of the Systems

Dried Air Systems
There are three common types of dried air systems: desiccant air dryers (replaceable system), pressure swing adsorption (PSA) air dryers (self-regenerative), and thermal swing adsorption air dryers (regenerating with heat). The purpose for each of these types is simply to remove moisture from the feed gas, so the output is composed of approximately 21% oxygen, 78% nitrogen, and 1% trace gases, very much like ordinary air except purged of moisture. Some common properties of air driers include:

- Input air is compressed to about 100 psi. About 70% of this air is recovered for use in the ozone generator. For equivalent ozone output, the required air flow is double that of the same sized ozone generator using oxygen as the feed gas.
- Air driers have components that require frequent maintenance in order to sustain performance.
- Air dryers can provide feed gas delivery dew points of -30 to -100° F if they are well maintained.

Oxygen-Fed Systems
Oxygen concentrators using pressure swing adsorption technology deliver dry, oxygen-enriched feed gas in a continuous flow. They are used in a wide range of applications, including healthcare for patients who require a higher rate of oxygen (e.g., to compensate for respiratory diseases like emphysema), where compressed oxygen is undesirable because it is heavier and more prone to accidents or failure.

- Oxygen concentrators use compressed air inputs, usually in the range of 25 to 90 psi, depending on the size of the unit. About 9% of this air is recovered in the oxygen-enriched feed gas, with almost all of the nitrogen in the input air vented to the atmosphere.
- PSA oxygen concentrators typically have very low maintenance requirements.
- The delivered feed gas is usually very dry, reaching a -100°F dew point.
- A typical output gas is composed of 93% oxygen, 3.1% nitrogen, 3.8% argon, and 0.1% trace gases.

3580 Sueldo Street, San Luis Obispo, California 93401
Phone 800.676.1335 | Fax 805.541.8459

Performance Efficiency: Oxygen is Better by a Factor of 2

There are many ways to quantify the basic advantage of oxygen feed gas over dried air from a purely performance point of view. But they basically restate the same capacity advantage of ozone sanitation with oxygen: oxygen fed systems are about twice as efficient for ozone generators of the same size.

The advantage of oxygen by a factor of 2 does vary somewhat based on the specific design characteristics of the system, but the basic rule holds across several ways of measuring efficiency:

> An oxygen-fed ozone generator will produce about twice the amount of ozone (grams/hour or pounds/day) as the same sized ozonator using dried air.
>
> An oxygen-fed ozone generator produces about ½ the gas flow as the same sized ozonator using dried air.
>
> An oxygen-fed ozonator will generate at least twice the concentration of ozone (% by weight) in the feed gas as a comparable ozonator using dried air.

The performance advantage of oxygen-based systems translates into better disinfection effectiveness and lower maintenance.

Disinfection Effectiveness: Oxygen Systems Deliver Cleaner Water

The purpose of the ozone disinfection system is to provide safe, healthy, clear water for aquatic animals. A properly designed system will deliver ozone effectively dissolved in the correct quantity to neutralize the organic and non-organic contaminants that threaten the animals and water clarity that facilitates patron viewing. This primary goal is best served by systems using oxygen feed gas.

Because the oxygen-based systems deliver ozone in higher concentrations, the ozone is better utilized. It can be delivered in higher volumes with more of it dissolved in the water. This higher mass transfer rate also means that there is less ozone off-gassing or need for non-dissolved ozone destruction, and the entire production process is safer. Because total gas flow is lower for given amounts of ozone, smaller booster pumps and smaller injectors can be used for a given disinfection impact.

Finally, the oxygen-based system is more easily managed and controlled. The quantities of ozone generated and the mass transfer rate can be set to desired levels of disinfection potential as determined by the size, temperature, turnover rate, salinity, and organic load of the aquarium.

Maintenance Efficiency: Oxygen Systems are More Reliable

The more efficient delivery systems using oxygen are also more reliable. It is known that systems using dried air have a tendency to produce nitric acid at 3 to 4 times the rate of oxygen-fed systems, which can lead to a higher incidence of corrosion in the ozone generator and other parts of the system. In part, this is because the molecular sieve used in modern oxygen concentrators is more efficient at removing moisture than the desiccant materials used in many air dryers.

3580 Sueldo Street, San Luis Obispo, California 93401
Phone 800.676.1335 | Fax 805.541.8459

On the positive side, the oxygen concentrators are sourced from the health industry, and are highly reliable. As noted above, the PSA design is the same as that used in portable oxygen sources for medical patients with compromised respiratory capabilities. For these individuals, mechanical failure is not an option to be tolerated.

Total Operational Efficiency Favors Oxygen Feed Gas

This efficiency advantage of oxygen over dried air translates into investment cost savings, a smaller footprint, reduced operational costs, and simplified management. In fact, many water disinfection programs that use ozone use oxygen feed gas or are shifting away from dried air to oxygen. New municipal and wastewater treatment plants use oxygen, and virtually all commercial pools use oxygen feed gas.

Since cost always matters, this purely operational advantage of oxygen feed gas has to be considered, but it has to be evaluated in the context of aquatic animal health.

Animal Health is the Point

The critical point is that oxygen feed gas delivers a healthier aquatic environment for all the animals in aquariums. None of the efficiency advantages of oxygen would matter if it didn't.

All ozone disinfection systems operate by dissolving ozone-enriched gas into the water body. In the dissolved state, ozone comes into contact with microorganisms or other contaminants and oxidizes them. However, the gas injected into the water is not pure ozone – it contains elements of the feed gas in dissolved state, and the composition of the feed gas is reflected in changes in water chemistry. The issue is how the injected dissolved gases might affect the animals in the aquarium.

Generally, a system using a feed gas that is 93% oxygen and only 3% nitrogen will result in more dissolved oxygen and almost no dissolved nitrogen being added to the water. Conversely, the dried air system will result in less dissolved oxygen and very high levels of dissolved nitrogen because the feed gas composition is similar to ordinary air, which is about 78% nitrogen.

Much higher levels of dissolved nitrogen may be dangerous to animals. Gas Bubble Disease, in this case, nitrogen narcosis, may result in animals that are living in water that is super saturated with nitrogen. The oxygen system does increase the level of dissolved diatomic oxygen as well, but because oxygen is used metabolically, there is less chance of gas emboli forming in the organism.

This higher level of dissolved nitrogen cannot be controlled in a dried air system output because it is not a product of the system and subject to measurement and control like either diatomic oxygen or ozone. In fact, the only way to control the levels of dissolved nitrogen effectively is to eliminate it from the feed gas, which is what oxygen concentration does.

DEL OZONE™
advanced sanitation solutions

3580 Sueldo Street, San Luis Obispo, California 93401
Phone 800.676.1335 | Fax 805.541.8459

Is Higher Dissolved Oxygen a Problem?
The short answer is no. Oxygen feed gas systems do increase the level of dissolved oxygen (DO_2) in the water, but not to dangerous levels. The absolute levels of DO_2 can be managed by the design of the system. Finally, somewhat higher levels of DO_2 can be beneficial to the aquarium life.

The longer answer requires a brief review of some aspects of ozone system design and water chemistry.

System Parameters and Dissolved Oxygen
The source of additional dissolved oxygen is the ozone disinfection system. In a maximum efficiency configuration, an ozone disinfection system using 93% oxygen feed gas would be injecting ozone-enriched gas into a sidestream of 20% (or less) of the circulation water. At 95% mass transfer efficiency at 15 psi contact/degas tank pressure, the maximum additional dissolved oxygen is 3.2 PPM (mg/l) in 20°C water, assuming no oxygen demand.

It is important to understand that these parameters reflect maximums under normal operating conditions. Further, they can be controlled through system design, for example by reducing the sidestream percentage. The level of ozone injected is monitored by an ORP controller, and can be adjusted to stay within desirable limits. However, in all cases, a properly designed commercial aquarium will provide the means to control super-saturation of any dissolved gases in the animal habitat.

Observed Levels of Dissolved Oxygen in Nature
To put the issue in perspective, consider the levels of dissolved oxygen found in natural bodies of water.

Salt water
Normal DO_2 level is 7.5 – 8.5 PPM (mg/l) at 20°C. A high level in seawater is 12 PPM.

Coral reefs
Normal DO_2 is 4 – 6 PPM (mg/l) at 20°C.

Fresh water
Normal DO_2 is 9 PPM (mg/l) at 20°C. A high level in fresh water is 10 PPM.

In an aquarium environment, DO_2 levels of 12 PPM or higher would turn the water milky, prompting immediate intervention to reduce the level. If permitted to reach dissolved oxygen of 20 PPM, animals would begin to die.

Aquarium Water has Oxygen Demand
Aquarium life needs dissolved oxygen. Therefore, the assumption about the ozone system injecting up to 3.2 PPM of additional dissolved oxygen under conditions of no oxygen demand is unrealistic. In fact, the oxygen provided at modest levels by the ozone system helps to maintain healthier water as well as cleaner water.

3580 Sueldo Street, San Luis Obispo, California 93401
Phone 800.676.1335 | Fax 805.541.8459

Water Quality Management
Every commercial aquarium requires a disinfection system that can be managed to meet water quality requirements. While every ozone-based system should be able to control the super saturation of dissolved gases in aquarium water, the control is more effective in an oxygen-fed system. The oxygen system not only avoids the potential threat of nitrogen poisoning, but can actually help to make water healthier through the side benefit of slightly increasing levels of dissolved oxygen.

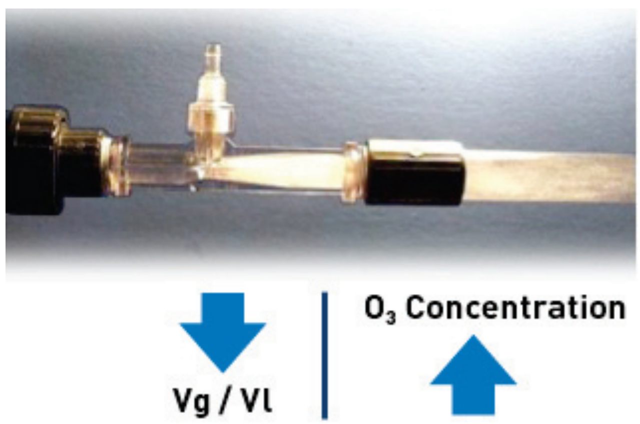
The oxygen feed gas approach to ozone disinfection is the result of over a century of research and experience. There is no good reason to revert to the older dried air method.

References

- International Ozone Association
- US Environmental Protection Agency (EPA)
- Louisiana State University
- Water Research Center
- Fish Disease – Diagnosis and Treatment- Edward D. Nova
- Steve Kaiser Vice President – Marine Science & Engineering Atlantis Resorts
- Dave Derk - Lead Life Support/Water Quality Brookfield Zoo
- Chart SeQual Technologies, Inc.
- AirSep Corporation, Inc.
- Mazzei Injector Corporation
- Cloward H2O
- RICE International Consulting Enterprises (Ozone Consultant)
- RKS Ozone Consultants
- DEL Ozone

DEL OZONE™
advanced sanitation solutions
3580 Sueldo Street, San Luis Obispo, California 93401
Phone 800.676.1335 | Fax 805.541.8459

Henry's Law Formula
$e^p = e^{kc}$
Where:
e = natural logarithm
p = partial pressure of the solute above the solution
c = concentration of the solute in the solution
k = Henry's constant
Taking the natural logarithm of the formula, gives us the more commonly used formula:
p = kc

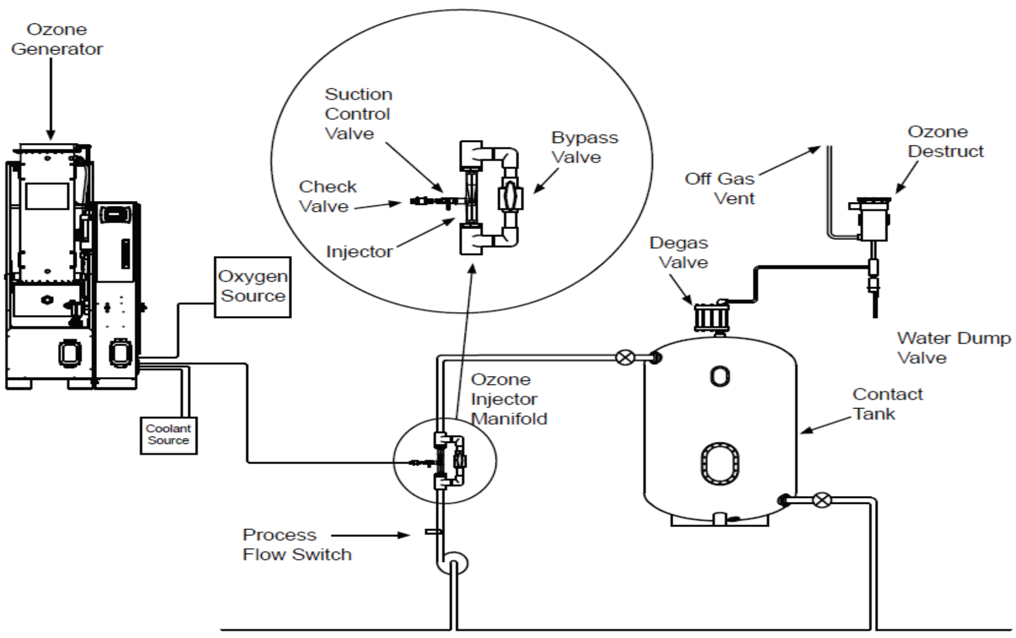


- The most efficient way to get the ozone into the water is to raise the O_3 concentration and lower the gas to liquid ratio (volume of gas/volume of liquid[Vg/Vl])

- Raising the ozone concentration, while lowering the gas to liquid ratio, and operating under the highest pressure available with the most aggressive mixing components provides the most efficient mass transfer

3580 Sueldo Street, San Luis Obispo, California 93401
Phone 800.676.1335 | Fax 805.541.8459

Basic Ozone System (without protein skimmer)



Basic Ozone System (with protein skimmer)