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Optimizing Mass-Transfer of Ozone Gas into Aqueous Solutions

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Ozone disinfection is critical for protecting life in an aquatic environment. However, not all ozone systems are built the same way, and the differences will impact the efficacy, safety and cost effectiveness of the system.

Ozone's benefits can only be realized when ozone is dissolved in water, so the critical issue is how efficiently the system manufactures and introduces ozone into an aqueous solution. This is defined as the mass transfer of ozone gas into the aqueous solution (or how well the ozone dissolves into the water).

There are two general engineering solutions to the mass transfer of ozone, and these define the type of system and its potential efficiency. One approach is to pump feed gas under pressure through the ozone generator and then through a diffusion system. The bubble diffusion method achieves only a low rate of mass transfer of ozone into the aqueous solution.

A superior method of mass transfer is possible using negative pressure to draw the feed gas through the ozonator, with mass transfer occurring through venturi injection. The water velocity passing through the injector creates suction which pulls the ozone gas into the water, and the turbulence at the point of injection greatly increases ozone's mass-transfer (or dissolution) into the water.

This paper amplifies the differences in the two engineering approaches to the mass transfer of ozone into aqueous solution.

Pressure

Ozone has been in use commercially as an antimicrobial oxidizer for aqueous solutions for more than 100 years. During the first 80 years or so, the most common way to introduce ozone into water was to bubble it under pressure into the bottom of a tall atmospheric water column through a bubble-diffuser (sometimes this was as simple as drilling many small holes in PVC pipe at the bottom of the water column). It is well known that the mass-transfer of gas into solution with this method is no more than 10% in a 20 foot or shorter water column. Therefore the balance of the ozone gas (or 90%) has little option other than to off-gas from the surface of the water.

Undissolved ozone gas is virtually useless in terms of antimicrobial efficacy in the water and the off-gas must be directed away from humans and sensitive equipment and consequently destroyed in a vacuum type ozone destruct system, as it is harmful to living things and many surfaces. Vacuum ozone-destructs are complicated, unreliable and expensive, and take up a large amount of space.

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Vacuum

During the last 25 years, the emergence of venturi injectors has all but eliminated the practical use of pressurized bubble diffusion systems in most commercial applications (with the possible exception of waste water treatment) and eliminated it completely in aquatic applications (whether the water's inhabitants are human or animal). In the past 15 years, venturi optimization has provided end-users with an ozone mass-transfer of greater than 90% (95-97% is not uncommon).

Venturi injection is accomplished with the use of an injector which has been sized to meet the required water flow of the vessel and the required gas flow of the ozone generating system. The injector is generally plumbed with a bypass manifold and is positioned in a side-stream portion of the water vessel's main recirculation flow.

The bypass manifold is configured to provide a pressure differential across the injector which creates suction, pulling the ozone gas through the venturi where it is dissolved in the water. Directly after injection, there is a degas vessel with a valve located on the top that is open to atmosphere and allows any undissolved gases to pass out of the system before the recirculating water returns to the main vessel. This small amount of air, oxygen and ozone is directed to a simple thermal/catalytic gaseous destruct system, which converts any ozone molecules back into harmless oxygen molecules. Once the undissolved gases are removed through the degas system, there are no bubbles passing into the body of water. See Figure 1
Now that we understand that the best way to introduce ozone into water is via venturi injection; it would seem logical to manufacture ozone under vacuum. However, it is much easier and less expensive to produce ozone under pressure, so that is what many manufacturers do. This creates undesirable issues that should be taken under consideration. These issues affect safety, antimicrobial efficacy and overall performance of the ozone system.

Safety

Ozone gas is a very strong oxidizer. In almost all countries there are gaseous ozone safety laws that limit human exposure to ozone gas to no greater than 0.1 PPM over an eight hour period for five days in a row and 0.3 PPM for any fifteen minute amount of time.

An ozone generator that produces ozone gas under positive pressure introduces the risk of off-gassing into an inhabited area if a gas line breaks. This off-gas can exceed the allowable levels of ozone by 100s of times. The only safety feature is the addition of a gaseous ozone monitor/controller that will disable the generator in an event of a leak, and will require extensive venting and isolation of the room in which the system is located as well as an audible and visual alarm.

An ozone generator that produces ozone gas under negative pressure (vacuum) does not have this risk. This approach is a preventative measure as opposed to a reactive one. If a gas line breaks, the system loses vacuum, the generator shuts down and isolates the ozone chamber so ozone cannot leak from the system. A properly designed generator will immediately shut down and isolate the ozone chamber so ozone cannot leak from the system. The use of a gaseous ozone monitor/controller with vacuum-manufactured ozone gas is a redundant failsafe.

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Efficacy

The mass-transfer performance of the injector is optimized when it is pulling a vacuum against a vacuum in lieu of trying to balance a pressurized system to convert to vacuum. It is well known that this optimization is even greater when the injector is pulling against a slight restriction from the ozone generator which further increases the mass-transfer of gas into solution. This is easily accomplished with a vacuum-type ozone generator.

Overall Performance

Only dissolved ozone gas performs readily as an antimicrobial oxidizer as well as provides oxidation of organic and inorganic contaminants in the water. It further provides significant reduction of chloramines (chlorine's ineffective and dangerous by-product) and assists flocculation which enhances filter performance. Clearly the best option for performance is ozone generated under vacuum.

Typical ozone plumbing configuration

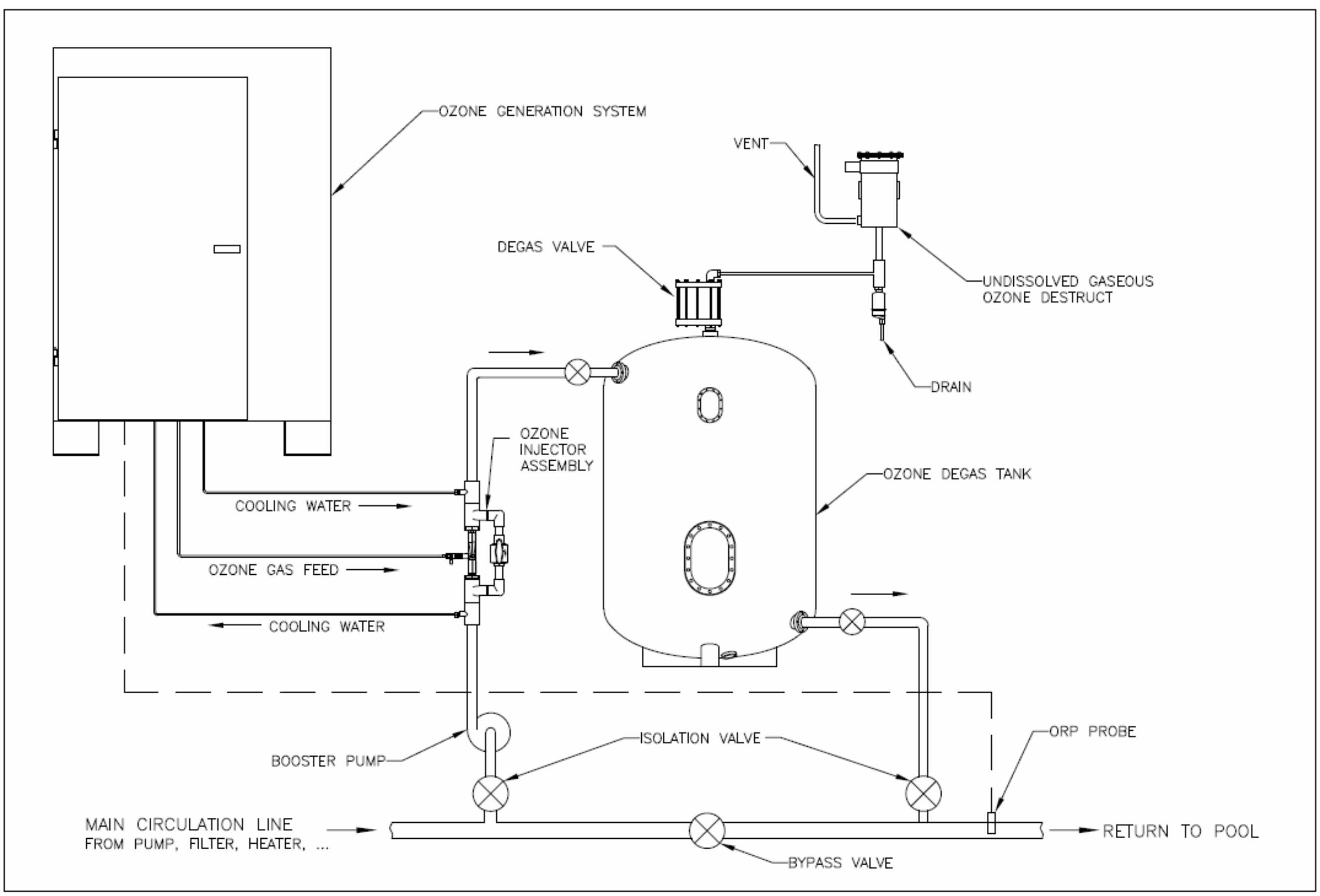

Figure 1