almost everything you need to know about

OZONE

in

COMMERCIAL WATER TREATMENT APPLICATIONS

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GENERAL INFORMATION ABOUT OZONE

The History of Ozone

Ozone(O3), an unstable, gaseous allotrope of elemental oxygen (O), is a strong, naturally occurring oxidizing agent. When ultraviolet rays from the sun strike oxygen molecules in the upper atmosphere, ozone is produced, thus creating the protective ozone layer around Earth shielding us from high levels of UV radiation. Lightning also produces significant quantities of ozone naturally in the atmosphere.

Ozone is not a new discovery and has a long history of use as a water sanitizer. In 1906, the city of Nice, France built the first municipal water purification plant utilizing ozone. More than 30,000 swimming pools in Europe are treated with ozone. In New Zealand and Australian pools, the ozone dosage has often been underrated and a proof of ozone output was usually not required. Some ozone suppliers will then claim that chlorine is needed anyway and use this as an excuse. In the past this has caused understandable mistrust and this explains why the use of ozone in New Zealand and Australia is at least 30 years behind Europe.

How Ozone Works

Ozone(O_3) is an unstable compound generated by the exposure of oxygen molecules (O_2) to ultraviolet radiation or a high energy electrical discharge. The weak bond holding ozone's third oxygen atom is what causes the molecule to be unstable and thus, very effective. Because of this instability an oxidation reaction occurs upon virtually any collision between an ozone molecule and a molecule of an "oxidisable" substance.

In water treatment these include dissolved minerals such as iron and manganese or various other water contaminants, organic compounds, bacteria, and viruses. In an oxidation reaction, energy is transferred to the ozone molecule leaving a stable oxygen molecule (O_2) and a highly unstable oxygen atom (O_1). The molecule being oxidized then bonds with the loose O_1 atom creating an oxide of the substance. Dissolved metals oxidize and are no longer soluble. The structure of an organic molecule is changed by oxidation which often causes the entire molecule to come apart (with some help from other ozone reactions). Bacteria and other micro-organisms are literally split apart by ozone and viruses are efficiently inactivated.

Ozone is highly reactive. In its gaseous form it will quickly corrode most metals (such as iron, mild steel, and copper), as well as cause damage to most plastics. Rubber exposed to ozone will quickly harden and crack. Gaskets, sealing compounds and piping must be chosen with care before being used with ozone (See Material Selection, page-7)
In swimming pool water at 20 °C, the half-life of ozone is less than half an hour. Decomposition is much more rapid at higher temperatures or if contaminants are present.

Ozone is soluble in water and thus efficient transfer of ozone into the water is critical for effective disinfection of pools and spas. Only dissolved ozone is able to oxidize contaminants in the water. Non-dissolved ozone *off-gases* to the surface and is lost. One of the most effective means of introducing ozone into a water stream is by use of a *Venturi injector.* The Venturi uses the water stream, *motive flow,* to produce a suction which draws ozone-containing gas into the water stream where it is violently mixed. This process produces very small bubbles of the ozone-containing gas, enabling the ozone to readily dissolve.

Ozone is frequently misdiagnosed and equated with low-altitude pollution. Nothing could be further from the truth. In fact, ozone breaks down pollutants and should be welcomed when found in the air.

Ozone Has Multiple Applications

It is used in thousands of residential and commercial pools and spas all over the world. The International Bottled Water Association (IBWA) recommends that all bottled water be treated with ozone. This provides disinfection for the water, the bottle, and the cap, leaving no residual taste, odour, or harmful by-product. Other common uses of ozone include:

- Treatment of Potable Water Supplies
- Aquatic Animal Life Support
- Aquaculture
- Surface Sanitation in Food Processing
- Wine barrel sanitation
- Fresh-Cut Produce Washing
- Mould / Mildew Control in Produce Storage
- Cooling Tower Water Treatment

- Odour Control & Smoke Elimination
- Pulp Bleaching
- Waste Water Treatment Perfume Manufacturing
- Kaolin Bleaching (Cosmetics)
- Ultra pure Water (Microchip manufacturing and Pharmaceuticals)

Benefits of Using Ozone

- Ozone destroys bacteria, mould and mildew, eliminates spores, yeast, and fungus, and inactivates viruses and cysts. There is no known micro-organism that is not killed by ozone.
- Ozone can significantly reduce levels of harsh chemicals such as chlorine.
- Ozone slowly decomposes to oxygen and remains dissolved in water up to the point of oxygen saturation. This makes pool water clean, sparkling and appealing.
- Ozone acts as a micro-flocculant aiding removal of organic waste, thus enhancing the effectiveness of sand filters – it also directly decomposes ammonia, oils and other bather wastes via oxidation.
- Ozone is pH neutral and does not affect the pH balance of water like traditional pool chemicals.
- Ozone leaves no unpleasant chemical taste, smell or other contaminants.
- Ozone dissolved in water will not irritate skin, eyes, nose, or ears, nor will it dry out or leave a chemical film on skin.
- Ozone can reduce chlorine or bromine consumption to a minimum, saving money on maintenance.
- Ozone is generated "on site", no storage, handling or dispensing as with other chemicals.
- Ozone's effectiveness can be measured with a simple ORP meter.

OZONE GENERATION

Two methods are commonly used for generating ozone: *ultra-violet* radiation and *corona discharge.* Ultra-violet (UV) generators, used for low concentration air purification or on small water volumes with low demand, are relatively simple and economical but limited in output capacity. Corona discharge (CD) generators are required for use in commercial pools or other systems with high oxidizer demand.

Ultra-Violet Ozone Generator

Historically most ozone generators used on small residential pools and spas have utilized the UV ozone generation method where ozone is produced by irradiating ordinary air with UV light at wavelengths below 200 nanometers (nm). Longer wavelengths (around 250 nm) of UV light are more efficient at destroying ozone rather than producing it. When enough UV energy is added to an O_2 molecule, it splits, freeing two O_1 atoms to collide with other O_2 molecules **c**reating ozone (O_3). Recent technological advances in high frequency electronic power supplies have allowed ozone generator manufacturers to develop small, efficient, and economical corona discharge ozone systems that displace UV technology altogether.

Corona Discharge Ozone Generator

In a Corona Discharge (CD) system, ozone is produced by passing oxygen-containing gas through a high voltage electrical discharge, or corona. A minimum of about 4,000 volts of electricity is necessary to create the corona (10,000 is a practical design maximum voltage). Oxygen passing through the corona absorbs energy, splitting the O_2 bond and freeing two O_1 atoms to re-combine with other O_2 creating O_3.

Commercial generators generally utilize concentrated oxygen (>90% pure) from an *oxygen concentrator* as the feed gas. The advantage of this is that the clean, dry oxygen gas maintains better operating conditions in the corona discharge cell prolonging its life and increasing its efficiency. Alternatively dry air (-70 °C dew point or less) may be used in some commercial ozone generators though the maintenance required on air driers often offsets the nominal additional cost of the oxygen concentrator.

Small CD generators such as may be used in small residential pools or portable spas generally use 'ambient air (containing 21% O_2) as the feed-gas. For these small systems it is generally not practical or economical to dry the air or use oxygen which limits their capacity. While suitable for 'low-end' residential use they are not generally producing enough ozone for commercial applications.

Ozone production can be regulated by adjusting either the applied power or feed-gas flow. By reducing the feed-gas flow, ozone concentration is increased, but overall production rate decreases. Reducing the applied power decreases concentration. The ozone/gas mixture discharged from the CD ozone generator normally contains from 1% to 3% (by weight) ozone when using dry air, and 3% to 6% (by weight) ozone when using concentrated oxygen as the feed-gas.

The feed-gas for a ‘high-end’ residential or commercial system must have particulate material and moisture removed as a minimum. Any contaminants present in the gas stream build up quickly and affect the electrical discharge. Moisture in the feed-gas causes two serious problems. First, moisture will cause a significant drop in ozone production due to ‘cell fouling’. Second, nitrogen in the air converts to oxides which then dissolve in moisture to form small amounts of nitric acid. Feed-gas must be dried to below -70 °C dewpoint to ensure that this does not occur. Moisture is usually removed by passing the air through molecular sieves or activated alumina.

Oxygen fed systems are preferred for a number of reasons. First, the nature of oxygen preparation equipment ensures particulate and moisture-free feed-gas. Second, the oxygen environment increases generator efficiency by making more O_2 molecules available for conversion to ozone. The clean environment created by the oxygen preparation system increases the life of internal components and significantly decreases the maintenance requirements of the system.

OZONE SYSTEM REQUIREMENTS

For efficient, effective and safe operation the ozone generator and its components must be combined with all of the following general components (see Figure 1):

- Ozone generator
- Injector / Injector Manifold
- Reaction Tank (Contact Tank) / Degas Tower
- Degas Valve
- Ozone Destruct

Peripheral equipment (such as plumbing, pumps, valves, etc.) is not included here other than to describe material requirements for reaction with ozone gas or dissolved ozone in water.

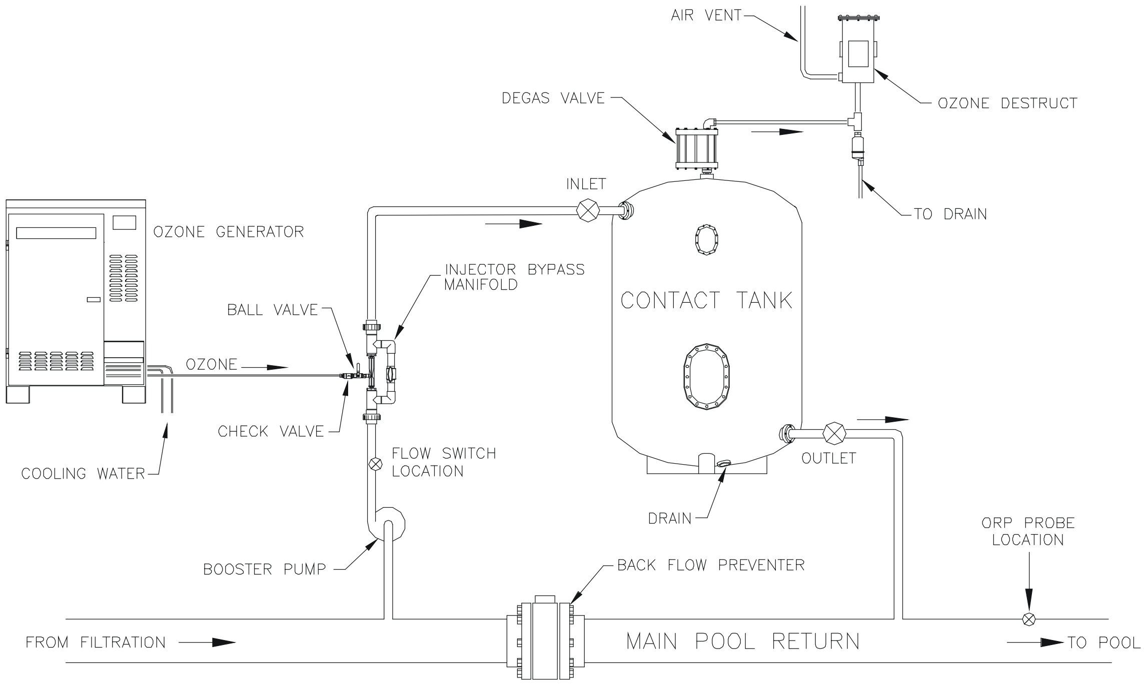

Figure 1: Sidestream ozonation system schematic diagram

Corona Discharge Ozone Generator Requirements

A well designed CD type ozone generator should include the following characteristics for safe, consistent, low maintenance operation and long service life:

1. Generator module must be constructed of all non-combustible and ozone resistant materials such as stainless steel, ceramic, glass, etc
2. Generator must be designed to maintain ozone under vacuum from generation to the point of injection in the water stream. Automatic feed-gas flow control should be incorporated to maintain a vacuum set-point and correct for vacations in suction. Minimum protection against vacuum loss should be included.
3. Water backflow protection must be included in the ozone gas delivery line. Ideally this is interlocked to the control system causing an immediate shutdown of all high voltage circuits and isolating the generator module if water is detected.
4. Automatic shut down should occur under any of the following conditions:
   Door open or cover panel removed from the generator cabinet
   Low feed-gas supply
   Loss of vacuum
   High temperature of the ozone generator module and high voltage transformer
   Loss of process water flow (including backwash cycle)
   High dew point in the feed air (not necessary if oxygen is used)
5. Ozone generators must be marked with legible and permanent identification showing:
   manufacturer and/or supplier
   model number
   serial number
   date of manufacture
   electrical requirements
   type of feed-gas
   rated feed-gas flow rate (SCFH, standard cubic feet per hour or Liters per minute)
   rated ozone production (Commonly in grams/hour or kg/day)
   rated ozone concentration (g O_3/hr, % weight or ppm)
   method of cooling and coolant flow rates
   wiring diagrams

Injector / Injector Manifold

Efficient ozone injection into the water is accomplished using the suction developed by a Venturi injector in the water stream. Systems which diffuse ozone into the water under pressure are far less efficient and generally considered less safe for pool and spa use due to the potential for ozone leaks.

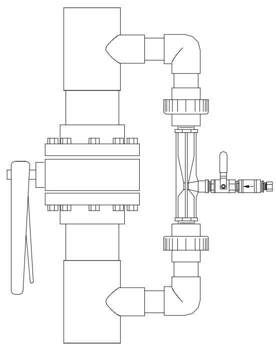

Figure-2: Venturi Injector Manifold

For proper operation, an injector must operate within a specific flow rate and pressure differential range. To accomplish this, it is usually necessary to provide a manifold assembly enabling adjustment of the injector's *motive flow* with a bypass valve (see example in Figure 2). A properly installed Venturi injector can provide 95+% *mass transfer* of ozone at the point of injection.

Contact Tank (Reaction Chamber) / Degas Tower

The *contact tank* (Figure 3) allows time for dissolved ozone to oxidize mineral and organic contaminants and to disinfect the water. For these reasons, the tank is designed in such a way as to retain the water and eliminate 'short circuiting' of the flow. The flow of gas bubbles should be in a direction opposite to that of the flow of the water for more effective dissolving of ozone in the water. The concentration (C, in mg/L) of dissolved ozone multiplied by the

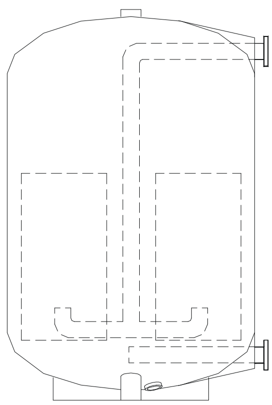

Figure-3: Contact Tank

time (T, in minutes) of contact between the dissolved ozone and the contaminants in the water provides a 'CT value.' This value is used as an index to the effectiveness of the disinfection process. Guidelines developed by the US EPA for applications such as drinking water, and OSHA for ozone safety in indoor environments, are generally accepted for use in sizing pool ozone systems as well. (See ozone Sizing and Chemical Reduction section p.9). Ozone disinfection systems (using ozone as the primary disinfectant and not merely as a water polisher or sodium bromide regenerator) achieve adequate disinfection with a CT of 1.6 or greater.

For example, a dissolved ozone value of 0.4 mg/L in contact with the water for 4 minutes provides a CT value of 0.4 x 4 = 1.6.

Adequate disinfection may not occur when:

- the quantity or concentration of ozone gas dissolved into the water is too low to reach the proper CT value
- the water temperature is too high (above 45 °C) causing rapid decomposition of ozone
- the microbiological and/or organic content of the water is too high for the available ozone
- the flow-through time allowed in the *reaction tank* is too low

Another critical function of the reaction tank is to provide a means of removing the undissolved gasses (off-gas) from the water stream. The ozone containing off-gas that bubbles up through the reaction tank must be collected and led safely through an exhaust line, through an ozone destruct unit, and off to atmosphere. If not, this gas will be entrained in the water flow and released, for example, into the atmosphere at the pool water surface.

Ozone Destruct

Ozone must be destroyed before it is vented to the atmosphere as a safety precaution and to comply with regulations. Therefore, ozone containing off-gas must be passed through an *ozone destruct.* This can be achieved by simply placing an ozone degas valve on a port at the top of the reaction vessel in a pressurized contacting system (see Figure 4) and allowing the pressure to force the off-gas through the destructor.

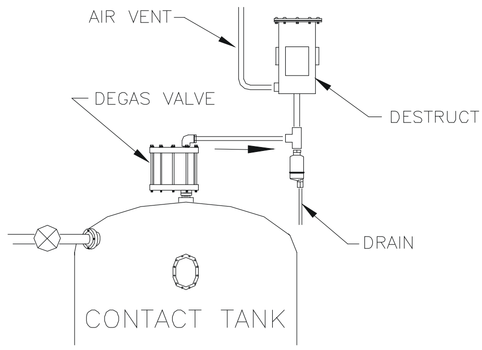

Figure-4: Ozone destruct

The gases leaving the destructor must be discharged well away from any air intakes or work locations. The pipe to the destructor must be approved for carrying ozone/air mixtures (See Material Selection, page 6) and must incorporate a water trap for collection and discharge of any liquid water escaping the contact tank or condensation forming in the line.

If the destructor does not work properly, high levels of ozone (0.2% or higher) can be discharged into the atmosphere. A blockage of the vent line (i.e. moisture freezing in the pipe), may result in a serious discharge of ozone into the ozone room.

Ozone in an off-gas stream can be destroyed in a number of ways, including (in order of preference):

- Catalytic: Passing the off-gas through a bed of manganese dioxide catalyst material causes conversion of ozone back to oxygen (O_2). This catalyst is extremely efficient at destroying ozone but must remain dry or it looses effectiveness. Any liquid moisture or oils in the off-gas must be removed prior to introduction into the catalyst bed. As the catalyst is not used up, recharging is only necessary when it has been contaminated by reactions with impurities or moisture in the gas stream.

- Thermal: Heating the off-gas to temperatures above 150 °C for at least 5 seconds. Thermal decomposition is simple but the power costs could be significant.

- GAC: Passing the off-gas through a bed of granular activated carbon (GAC) which will destroy the ozone in a slow combustion process, resulting primarily in the production of carbon dioxide. This method is not acceptable in most commercial applications, especially oxygen fed systems due to possible fire hazards associated with heat generated in the carbon/ozone reaction.

- UV Irradiation: UV light having a wavelength of 254 nanometers is fairly efficient at destroying ozone, particularly when the temperature is very low, below 0 °C.

Material Selection

The strong oxidizing power of ozone must be considered when choosing materials for pipes, valves, gaskets, pump diaphragms and sealant. Materials for water piping, tanks and other vessels must be resistant to corrosion and chemical attack. Materials for ozone gas conveyance must be nearly completely inert, moreso at higher concentrations as in commercial/industrial applications.

Some suitable materials and their uses are:

For Ozone/Air or Ozone/Oxygen:

Concentrations above 2500 ppm (0.4 % wt)

- PTFE, FEP (Teflon) - tubing, o'rings, or ozone cell materials
- PVDF (Kynar) - tubing, injection, check valves, etc.
- Stainless Steel, grade 316L - tubing or ozone cell materials
- Glass and most ceramics - ozone cell materials
- Aflas - seals, o'rings, gaskets

Concentrations below 2500 ppm (in addition to those above)

- Viton - tubing, seals, o'rings
- Kel-F - seals & o'rings

Note: Stainless steel tubing should only be used when the feed-gas is dried to a dewpoint below -60 °C and where no chance of water ingress exists. Corrosive acids formed in moist air will corrode the pipes from the inside.

For dissolved Ozone in Water (in addition to all those listed above):

- PVC or CPVC (Schedule 80)
- EPDM (Ethylene - propylene terpolymer)
- PVDF (Polyvinylidene Fluoride), Kynar (Pennwalt patent)

Gaskets and O'rings

- Aflas, Kalrez, and Teflon are acceptable gasket materials for both gas and aqueous seals.
- Viton, EPDM, and "Red Silicon" do not provide sufficient resistance to deterioration at ozone concentrations above 1.5% (gaseous) but work well in aqueous ozone solutions. If used for gaseous application these should only be used in static seals and replaced regularly.

Joint Sealing

Properly applied Teflon 'thread' tape may be used successfully for sealing joints. However, threaded fittings should be avoided. It has been found that Hypalon and silicone sealers which do not contain a rubber filler are also successful.

OZONE SIZING AND CHEMICAL REDUCTION

Successful application of an ozone system on commercial pools and spa pools can only be accomplished when the following charter is maintained:

Install an ozone system that provides the highest oxidation and disinfection of water while ensuring that no ozone enters an area where humans, equipment, or the environment are endangered.

There are varied opinions on the best way to address ozone system and reaction tank sizing for commercial pools and spa pools. Historically, in the US, these guidelines have been vague or nonexistent regarding the application of ozone on commercial pools and spa pools. However, the US EPA and OSHA have developed a solid range of criteria for other applications such as drinking water, industrial uses and human safety issues regarding ozone off-gas. There are also established guidelines for safety issues of maximum levels in and around commercial pools and spa pools. Therefore ozone system designs must address both proper sizing of equipment for disinfection and ensuring human safety as they relate to these guidelines.

The US EPA has established a basis for a three log inactivation (99.9 percent) for *Giardia* cysts in drinking water at certain temperatures (0.5C – 25 °C) and pH values of between (and including) 6 to 9. These numbers take into account the amount of ozone residual in the water for a determined period of time without filtration. The product of concentration (C, in mg/L or ppm) and contact time (T, in minutes) yields the CT value which indicates the effectiveness of the disinfection process. As an example, 0.4 mg/L (ppm) ozone applied and maintained for four (4) minutes equals a CT value of 1.6. The CT value is then applied to different organisms to determine the three log inactivation of that organism. (See Table 1)

	Temperature °C					
Inactivation	**0.5**	**5**	**10**	**15**	**20**	**25**
1.0 log	0.97	0.63	0.48	0.32	0.24	0.16
1.5 log	1.5	0.95	0.72	0.48	0.36	0.24
2.0 log	1.9	1.3	0.95	0.63	0.48	0.32
2.5 log	2.4	1.6	1.2	0.79	0.60	0.40
3.0 log	2.9	1.9	1.4	0.95	0.72	0.46

Source: U.S. EPA (1989A)

Table 1: Proposed U.S. EPA CT values (mg x min/l) for the Inactivation of *Giardia* Cysts with Ozone at Different Temperatures and pH values from 6 to 9.

For example, a CT value of .72 provides three logs of inactivation (99.9%) *of Giardia* cysts at 20 °C (room temperature) and a CT value of 1.4 provides 99.9% inactivation at 10 °C. As determined in Table 1, the *higher* the temperature, the faster the reaction time and *lower CT value* is required. In addition, protozoan cysts are much more resistant than vegetative forms of bacteria and viruses. Therefore, when the CT value of ozone is sufficient to inactivate the more resistant organisms, it will be more than adequate to inactivate the less resistant organisms.

Giardia is typically used as the benchmark. However, testing done on *Cryptosporidium* inactivation shows results with a 1.1 1 mg/L (ppm) residual of ozone and a five minute contact time, or a CT value of 5.55 at 20 °C water temperature. In situations when *Cryptosporidium is* present, this larger CT value should be considered.

European standards for pool water are much higher than U.S. standards, particularly Germany, which are close to drinking water. French and Canadian governments (to name two of many) have adopted the same CT standard (1.6) for their pools as the U.S. EPA has established for drinking water guidelines. The major differences between standards for pool water and drinking water are as follows:

1. In most states commercial pool circulation is closed loop, providing repeated exposure with at least four passes per day vs. a single pass as used in the EPA testing.
2. The *demand* for oxidizer in the water increases with each bather added and the environmental contamination.
3. Pool and spa pool water temperature is typically warmer, 25 to 40 °C, than values in Table 1.
4. Disinfectants such as chlorine or bromine are added and maintained in pools and spa pools.
5. Off-gas issues need to be addressed to eliminate the possibility of airborne ozone where humans and equipment are present.
6. Pool water is filtered.

Consequently, most government agencies have adopted the US EPA accepted CT value of 1.6 for sizing ozone systems on commercial pools and spa pools as the main disinfectant. Though it appears that a lower CT may be sufficient the addition of continuous contamination (bathers and environmental conditions or demand) creates the need for the higher CT value of 1.6 when the ozone system is designed to complete 100% disinfection. Using the CT of 1.6 typically reduces chlorine use by approximately 60 to 80%. An ozone system that provides less than a CT value of 0.8 or a system that provides less than 0.5 mg/L (ppm) with less than one minute contact time is merely a water polisher or 'chemical system' (such as an “ozone/bromine system" which uses the ozone only to reactivate the sodium bromide into hypobromous acid and provides no significant chemical reductions.)

Modern systems commonly employ Venturi induction in a *side or slipstream* to introduce ozone into the water. Considering ozone's saturation in 20 °C pure water is approximately 30 mg/L (ppm), and dose levels of about 0.4 to 1.5 mg/L, the difference between ozone dissolution capacity and the mass of ozone provided is very great. This ensures high mass transfer with no over-dosing (or waste) of ozone. Given a properly sized reaction tank and a 4 hour minimum turn over rate, a 15 to 25% side or slipstream provides adequate mass transfer of ozone into solution and sufficient contact time before entering the main stream. Water in the side or slipstream is disinfected with high ozone concentrations and then remixed with the main stream where further oxidation reactions occur. Because the side or slipstream water is diluted by a factor of at least three to one in the main stream, less ozone will enter the pool or spa pool and less ozone off-gas can occur. This system ensures a low ozone residual in the pool or spa pool at any given time.

Considering the previous information, it is prudent to note the significant superiority of ozone over other sanitizers such as chlorine.

Table 2 shows values of specific coefficients of lethality for four main disinfectants.

Table 3 shows CT values for 99 percent inactivation of microorganisms with ozone and free chlorine at 5 °C.

Disinfectant	Enterobacteria	Viruses	Bacterial Spores	Amoebic Cysts
O3 Ozone	500	5	2	0.5
HOCL Hypochlorous acid	20	1 up	0.05	0.05
OCL- Hypochlorite ion	0.2	<0.2	<0.0005	0.0005
NH2CL Chloramine	0.1	0.005	0.001	0.02

Source: Morris (1975)
Table 2: Values of Specific Coefficients of Lethality for the Main Disinfectants (L/mg/min),

Microorganism	Disinfectant			
	Free Chlorine	Preformed Chloramine (pH 8 - 9)	Chloride Dioxide (pH 6 - 7)	Ozone (pH 6 - 7)
E. Coli	0.034-0.05	95-180	0.4-0.75	0.02
Polio 1	1.1-2.5	770-3750	0.2-6.7	0.1-0.2
Rotavirus	0.01-0.05	3810-6480	0.2-2.1	0.006-0.06
Phage f2	0.08-0.18			
G. lamblia cysts	47-150			0.5-0.6
G. muris cysts	30-630	1400	7.2-18.5	1.8-2.0

Source: Hoff (1987)
Table 3: CT Values (mg/L x min) for 99 Percent Inactivation of Microorganisms with Disinfectants at 5 °C.

Sizing Calculations

Ozone Generator

Generator Sizing Formula:

Total m3/hr x dose rate = Grams Ozone per hour

Example:

500,000 Litres pool to be dosed with ozone at 0.4 mg/L (ppm)

For a four hour turn over, total circulation flow: 500 (m3) / **4** (hr) = 125 m3/hr = 2,083 L/min

Thus: **125 m3/hr x 0.4 g/m3 = 50** grams per hour

Reaction tanks

Reaction Tank Sizing Formula:

(Total L/min) x (% side stream) x (reaction time) = size of tank in Litres

Example:

500,000 Lire pool at a four hour turn over, 25% side stream and 4 minutes of reaction time.

2,083 L/min x 0.25 % x 4 min = 2,000 Litres tank

Method of Injection (vacuum only)

Injectors are sized by calculation in relationship to the liters per minute of the side or slipstream pump, the kPa or head on the inlet and outlet and the rated L/min (SCFH) of the ozone generator.

Ozone Destruct

Ozone Destruct must be sized in accordance with the ozone output of the generator and can service multiple degas valves in the event of multiple systems, providing the ozone output rating of the degas system is met.

Summary

Assuming the criteria are to size the ozone system as the primary sanitizer/oxidizer, the CT value of 1.6 is widely accepted. Further assuming pool and spa pool water to be in the range of 20 to 35 °C, it has been shown that a CT value of .46 is adequate. However, EPA CT values are developed in water that does not have a continuous load and may not take into consideration the added environmental contamination. Since it is not practical to provide a pilot study for every pool, some "Rules of Thumb" have been established from previous pilot studies and commercial pool experience over the past 50 to 60 years, with the final accepted CT value of 1.6. With the development of accurate ORP controllers, levels of ozone in the water can be accurately maintained while controlling off-gas levels.

Practical System Recommendations:

- 1.6 CT value (.4 mg/L (ppm) for four minutes)
- Generator sized to previous formula with 4-6% by weight concentration
- 15 - 25% Side or slipstream flow
- Vacuum injection
- Reaction tank to provide four minutes of contact time
- Undissolved ozone degas
- Undissolved ozone destruct
- ORP controller/monitor to maintain 850 millivolts (0.4 mg/L dose) after reaction tank (see Figure 1 p. 4)
- ORP controller/monitor to provide safety limit before pool or spa pool (see Figure 1 p. 4)
- Ambient ozone monitor to provide safety in the pool or spa pool and equipment room.

Side or slipstream is treated with a 1.6 CT value; undissolved ozone is degassed and destroyed; water is then diluted into the main stream to provide minimum ozone in the pool. The ORP controller provides ozone cycling on and off in conjunction with the bather load to ensure consistent amounts of ozone in the water for proper oxidation and disinfection. Residual oxidizer may be reduced to 0.5 - 0.8 ppm for chlorine and 1 - 1.6 ppm bromine (check with local health department as requirements may vary.)

Other options can include:

Carbon destruct of the side or slipstream water before returning to the main flow which destroys all dissolved ozone as well as all other oxidizers.

Lower doses and lower contact time for less reduction of residual chemicals. However, the longer the contact time before any residual oxidizer is added the more efficient the system.

German DIN method of full flow ozonation, reaction time, GAC filtration, and finally addition of a residual chemical oxidizer prior to return to the pool. This method has been in use in Germany for many years but is significantly more costly than the slipstream method.

Ozone Dose mg/l (ppm)	Contact Time (CT) in minutes	Approximate % Reduction Chlorine/Bromine
1.0	4.0	> 85%
0.8	4.0	80%
0.4	4.0	70%
0.2	4.0	65%

Table 4: Chemical reductions

The previous numbers are very close approximates based on practical experience and case studies. As bather load and environmental conditions vary, so may the percent of reduction of residual chemicals, such as chlorine and bromine. Contact time plays an extremely important role in percent of reduction. The longer the contact time before the addition of the residual oxidizer dose, the better the percent of reduction of the residual oxidizer.

Systems providing less than 0.2 mg/L (ppm) ozone (or systems utilizing small amounts of ozone to reactivate bromine) are not ozone disinfection systems but act as ozone *oxidizer* systems.

These inexpensive systems should be assisted with 0.2 ppm chlorine and with a 0.1 ppm ozone dose rate to provide partial removal of organic waste by flocculation of most of the organics. This is frequently seen in (low bather load) domestic pools where a 0.1 ppm dose rate and no contact tank provides excellent water quality.

Because the systems described in this paper all contain ORP controllers, overdosing is eliminated. If the bather load and environmental conditions are extremely high, or pool and water chemistry maintenance is poor, percent of chemical reduction may decrease accordingly.

OZONE ROOM DESIGN

Following is a summary of Ozone room design requirements as outlined in the Uniform Fire Code **(UFC)** (Note that these requirements only apply to 'high output' oxygen driven machines and do *not apply to 'low output air dryer type' machines which operate under suction*)

General Requirements

The ozone generator, oxygen concentrator and associated equipment shall be housed in an approved cabinet, or ozone room. Work stations, maintenance and repair benches shall not be located within an ozone room. The ozone room shall provide unobstructed access for maintenance staff to all pieces of equipment. There shall be sufficient clearance to permit repair or replacement of any equipment in the room. The room shall not be used for storage of chemicals, solvents or any combustible materials. The ozone room/cabinet shall be clearly identified by sign(s) stating, OZONE GAS GENERATOR - HIGHLY TOXIC - OXIDIZER. Ozone room shall remain locked with access for authorized personnel only.

Ventilation Requirements

Ozone rooms shall be mechanically ventilated with a minimum of six (6) air changes per hour 150 mm from floor level (or per local code). Exhaust from ventilation shall not be vented near HVAC equipment or other building openings. An adequate supply of make-up air shall be provided. The make-up air supply shall not be less than the air exhausted.

With *vacuum* operated ozone generators, utilizing a negative pressure (Venturi) ozone delivery system, any leak or break in the system after the generator allows air to be drawn into the system eliminating the potential for ozone release . This condition reduces or stops feedgas flow through the generator, thereby reducing or stopping the production of ozone. Because the danger of over-exposure to ozone is virtually eliminated in a vacuum driven system over pressure-fed systems, other operating equipment (such as sand filters, furnaces and pumps) may be located in the ozone room.

When an ozone generator is operated under *pressure*, any leak or break in the system will immediately cause ozone to be discharged into the ozone room. For this reason, the ozone room shall not contain any other auxiliary equipment. If the ozone room is a separate room, all openings (walls, ceiling, electrical conduits, access ports, monitoring apparatus, etc.) shall be tightly sealed.

Electrical Requirements

The ozone room shall have adequate illumination and emergency lighting. Lighting and exhaust ventilation switches shall be mounted outside the ozone room. Also, there must be an emergency electrical shut-off for the ozone generator in a safe and readily accessible location outside the ozone room. This enables the operator to shut down and lock out the generator without having to enter the room.

The ozone generator shall be designed to automatically shut down under the following conditions:

- When the process using generated ozone is shut down
- Failure of the ventilation system.
- Failure of the ambient ozone detection monitor

MONITORING

Ozone in Air

a) Ambient Ozone Monitor

i) Shall measure the level of ozone present in the room where ozone equipment is located, and raise an alarm when the ozone level exceeds a level of 0.1 ppm and shall shut down the ozone generator a high level of 0.3 ppm.

ii) The monitor shall include both visible and audible alarms and provide contacts for use in activation of exhaust fans and shut down of the ozone generator.

iii) The ozone monitor shall have a range of 0-10 ppm/volume with accuracy within 3% of actual.

iv) The monitor shall employ an electrochemical gas diffusion sensor requiring no expendable reagent placed 500 mm off the floor.

b) Detector Tubes with Volumetric Pumps

Airborne ozone concentrations may be measured using detector tubes. These are ’grab samples’ and give only an estimate of the concentration at the time the measurement was made. The tubes CANNOT be re-used. Detector tubes have a limited shelf-life (one or two years) and must be replaced at regular intervals (see the manufacturer’s instructions). Workers shall be properly trained in the use, maintenance and limitations of these measuring devices. This includes how to check the operation of the hand pump before each use by using an unopened detector tube.

Ozone in Water: Ozone concentration in water can be measured in two different ways.

a) Oxidation Reduction Potential (ORP) monitor measures the effective biocidal activity of oxidizer (dissolved ozone) in water in millivolts and can be converted to mg/L (ppm). ORP is the preferred method in pools and spas due to relatively low maintenance sensors and moderate cost.

b) Dissolved Ozone (DO3) monitors directly measure levels of dissolved ozone in water. These are relatively expensive and high maintenance. Recommended for use in critical applications where precise dissolved ozone level control is necessary.

Air Flow Monitoring

Flow meters are installed to measure the air flow into or out of the generator. Where more than one Venturi is pulling the ozone/air mixture from the generator, an air flow meter should be installed at each Venturi.

Note: Flow meters placed in the ozone gas stream must be made from materials compatible with high concentrations of ozone (see Materials Selection, page 7)

INTERPRETATION OF TERMS

Allotrope - A chemical element that can exist in two or more forms.

Booster Pump - Pump providing water flow through a Venturi injector, thereby creating a suction and drawing the ozone/air mixture from the ozone generator.

Contact Tank - See Reaction Tank.

Corona Discharge - A bluish visible electric discharge. A portion of oxygen passing through this discharge is converted to ozone.

***Cryptosporidium* *cyst* -** An infectious, complex parasitic protozoa, typically very difficult to kill.

CT Value - Ozone concentration in mg/L (pprn) multiplied by contact time in minutes.

Demand or Oxidizer Demand - That which constitutes contamination in water.

Dewpoint - Temperature at which water vapor present in air begins to condense (dew begins to form).

DIN - Deutsche Industrie Norm (German Engineering Standard).

DO3 Monitor- A sensor and monitoring instrument to measure the amount of dissolved O3 in water

***Giardia* cyst -** An infectious, complex parasitic protozoan.

Injector - A device through which the ozone/air mixture from the ozone generator is drawn under vacuum into the water. It provides for mixing and dissolving of ozone into the water.

Mass Transfer - Dissolution of gas into liquid.

Motive Flow - Water flow through a Venturi injector that provides suction at the ozone injection port of the injector.

Off-Gas - The undissolved ozone in air collected from the contact (reaction) tank(s) which must be passed through ozone destruction and safely vented to the outside atmosphere.

Oxidation Reduction Potential (ORP) - A measure of the ability of a solution to act as an oxidant and a disinfectant.

Oxygen Concentrator - Operates on a pressure swing adsorption (see PSA below) cycle utilizing a molecular sieve material capable of adsorbing moisture, nitrogen and carbon compounds.

Ozonation - The process of ozone reaction with another substance.

Ozone - A molecule consisting of 3 atoms of elemental oxygen. A powerful oxidizer and disinfectant.

Ozone Destructor - A device for destroying ozone in air before discharge to atmosphere.

Pressure Swing Adsorption (PSA) - A process using a molecular sieve material to adsorb nitrogen and moisture from air. Cycle is completely regenerative requiring little or no maintenance.

Reaction Tank (Contact Tank) - A tank in which dissolved ozone reacts with contaminants in the water. It may have a series of compartments or a single, large chamber with internal piping or baffles to inhibit short circuiting of the water stream.

Redox Potential (RP) - See ORP.

Side or Slipstream - A portion of the main water flow used for the introduction and contact time of ozone.

Three log Inactivation- 99.9% kill rate for Giardia cysts in drinking water

Venturi or Venturi Injector- A device in a fluid stream which creates a suction to draw the ozone/air mixture from the ozone generator into the water and provide efficient mixing of the two. (Compare with INJECTOR).

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