THEDEFINITIVEGUIDE
TOUNDERSTANDING

# OZONE

OZONE SOLUTIONS
The element of success.

ozonesolutions.com

## READING THE OZONE GUIDE

You are reading the first ever online ozone guide. We have created this guide to help you understand and appreciate ozone. This reading is meant to be fun and expand your mind with ozone possibilities. Enjoy!

## QUICK REFERENCE KEY

? Indicates a unique question with answers that most people will find interesting

! Indicates information that ozone beginners and experts will find interesting

Indicates information that challenges even those that consider themselves ozone experts, it will challenge your existing "ozone world view"

Thumbs Up – Indicates tips for good Ozone System design

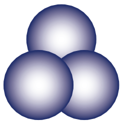
Indicates an online learning opportunity. Click the button to learn more or visit the url shown.

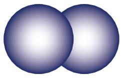
LEARN MORE

If you find an incorrect fact in this guide, please email us at **info@ozonesolutions.com**

# TABLE OF CONTENTS

# PROPERTIES OF OZONE VS. OXYGEN





| PROPERTY | OZONE | OXYGEN |
|---|---|---|
| Molecular Formula | $O_3$ | $O_2$ |
| Alternate Names | Triatomic Oxygen | -- |
| Molecular Weight | 48 | 32 |
| Color | Light Blue | Colorless |
| Characteristic Smell | "Electrical" Odor | -- |
| Solubility in Water (0° C) | 0.64 | 0.049 |
| Density (g/l) | 2.144 | 1.429 |
| Boiling Point | -111.9° C | -183° C |
| Flash Point | Not Applicable | Not Applicable |
| Auto-Ignition Temperature | Not Applicable | Not Applicable |
| Flammability | None | None |
| Electrochemical Potential (eV) | 2.07 | 1.23 |

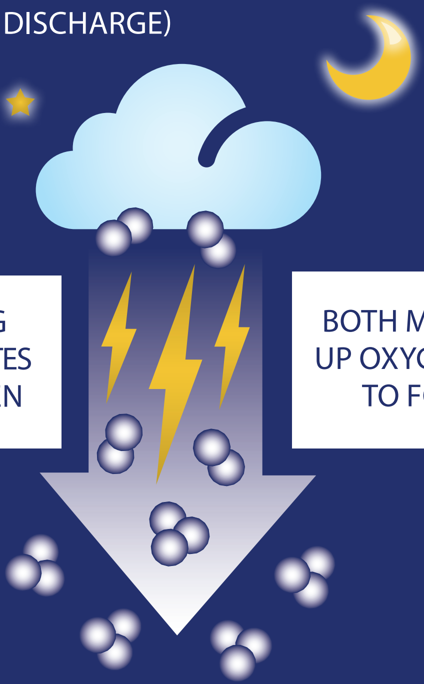
?

Did you know that the ozone layer is not really a layer but is a collection of ozone molecules in the lower portion of the stratosphere, 12-20 miles above the earth? If all these ozone molecules settled on the earth's surface, they would only be 1-inch thick!

All commercial planes and military jets have special filters to remove ozone from the air which permit passengers and pilots to breathe at these high altitudes. You didn't think that you kept breathing the same air over and over, did you?

## HOWISOZONEMADE?DIDYOUKNOWTHATOZONEISMADEINNATURE?ITNATURALLYDOESITINTWOWAYS.

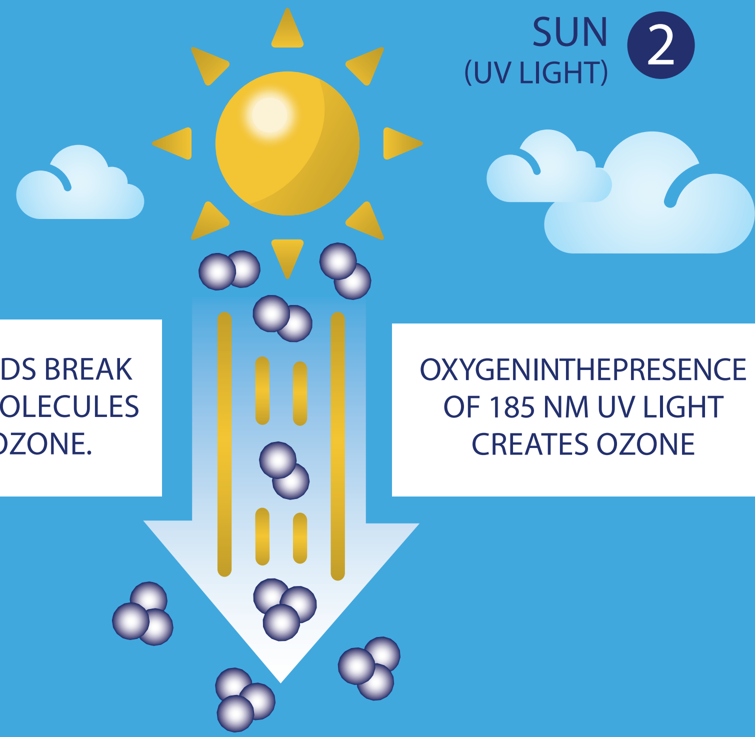
### 1 LIGHTNING
(CORONA DISCHARGE)



LIGHTNING PASSING THROUGHTHEAIRCREATES OZONE FROM OXYGEN

BOTH METHODS BREAK UP OXYGEN MOLECULES TO FORM OZONE.

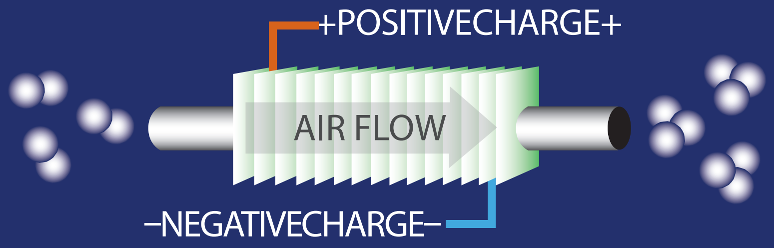
### SUN 2
(UV LIGHT)



OXYGENINTHEPRESENCE OF 185 NM UV LIGHT CREATES OZONE

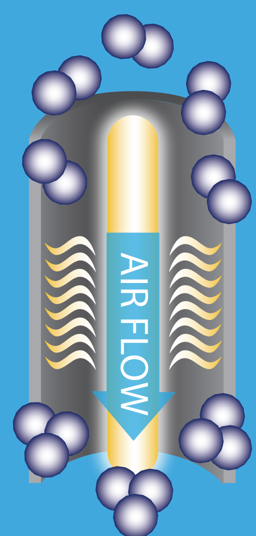
## HOW DO WE MAKE OZONE? SAME METHODS AS ABOVE, BUT ON A MUCH SMALLER SCALE

### 1 CORONADISCHARGE




OXYGEN,FROMTHEAIR,ISFORCED BETWEENHIGHVOLTAGEPLATES TOSIMULATECORONADISCHARGE. THEOXYGENISBROKENAPARTAND RECOMBINES INTO OZONE.

ADVANTAGESOFCORONADISCHARGE
- Generateshighozoneconcentrations
- Best for water applications
- Fast organic (odor) removal
- Consistent ozone output




### UVLIGHT 2

OXYGEN TURNS INTO OZONE AFTER IT IS HIT WITH 185 NM UV LIGHT FROM A UV BULB.

ADVANTAGESOFUVLIGHT
- Simple construction
- Lowercostthancoronadischarge
- Outputlessaffectedbyhumidity

The first patent for an Ozone Generator was by Nikola Tesla in 1896.

Did you know that a single lightning strike can create over 300 pounds of ozone?

# ADVANTAGES OF OZONE

- Ozone is the most powerful oxidant for disinfecting water or sanitizing surfaces
- Ozone can kill pathogens in seconds vs. several minutes for other oxidants
- Ozone is one of the strongest oxidants available for oxidizing organics
- Ozone decomposes into oxygen
- Ozone, by itself, does not affect pH
- Ozone cannot be stored, therefore, having a large volume of a dangerous oxidizer is not possible
- Ozone is excellent at oxidizing metals such as iron, manganese, and more
- Ozone enhances the flocculation and coagulation of organic material and consequently increases efficiency
- Ozone can be effective in partially oxidizing organics in the water to biodegradable compounds that can be removed by biological filtration

| OXIDIZING AGENT | OXIDIZING POTENTIAL |
|---|---|
| OZONE | 2.07 |
| HYDROGEN PEROXIDE | 1.77 |
| PERMANGANATE | 1.67 |
| HYPOCHLOROUS ACID | 1.49 |
| CHLORINE GAS | 1.36 |
| HYPOBROMOUS ACID | 1.33 |
| OXYGEN | 1.23 |
| BROMINE | 1.09 |
| HYPOIODOUS ACID | 0.99 |
| CHLORINE DIOXIDE | 0.95 |
| HYPOCHLORITE | 0.94 |
| CHLORITE | 0.76 |
| IODINE | 0.54 |

Source: water.epa.gov.lawsregs.rulesregs.swda.mdbp/upload/2001_01_12_mdbp_alter_chapt_3.pdf

In the summer of 1993 a cryptosporidium outbreak in Milwaukee, WI, resulted in the largest waterborne disease outbreak in documented United States history. An estimated 400,000+ were ill with over 100 deaths attributed to this outbreak. Chlorine, the primary disinfection technology, was useless against this cyst. A 55 million dollar ozone system was installed and effectively killed this organism. Milwaukee has not had an outbreak since!

Want to know the estimated financial cost of this outbreak?
Click to learn about Milwaukee's financial cost of not using ozone:
http://wwwnc.cdc.gov/eid/article/9/4/02-0417_article?utm_source=Ozone+Book&utm_medium=qrcode&utm_campaign=Ozone%20Book

LEARN MORE

# NEGATIVES OF OZONE

Like every oxidant, ozone has its downsides. However, it is important we clarify the actual negatives vs. the perceived "negatives" that arise from misuse.

**Commonly stated "negatives":**

- Oxidizes materials
- Material degradation
- Can harm people, pets, plants

In light of ozone's effectiveness, are the three bulleted items really negatives, or do we just need to use it safely like electricity, or gasoline? All oxidizers will have a similar "negative" effect as ozone if used improperly. Proper implementation is key to achieving outstanding results in your process.

**The real negatives are listed below:**

**Half Life**

- Ozone is an unstable molecule which quickly changes back to oxygen. The half-life (time for half of the ozone in air to decompose) is 20-60 minutes depending on the temperature and humidity of the ambient air. The half-life in clean water is about the same. Note: the temperature, pH, and water quality will affect half-life.

**Storage**

- Ozone cannot be stored or transported, and must be made on site. This requires feedgas preparation and ozone generation equipment.
- When is a negative a positive? Since ozone cannot be stored, it is not possible to have a large, potentially dangerous volume of oxidizer such as you can have for chlorine or hypochlorite. Ozone equipment can neither be "punctured" with a fork lift nor "tipped over."

## HALF LIFE OF OZONE

Dissolved in Water (pH 7)

| F° | C° | TIME |
|---|---|---|
| 59 | 15 | 30 MIN. |
| 68 | 20 | 20 MIN. |
| 77 | 25 | 15 MIN. |
| 86 | 30 | 12 MIN. |
| 95 | 35 | 8 MIN. |

Research References:

"Ozone – A Reference Manual" by www.wqa.org

"Supplementary Swimming Pool Treatment" by Poolpakinternational.com – MK2_PTL_OZONE_Rev-20110527.pdf

# OZONE SAFETY

Ozone is a strong oxidizer that is generally not harmful to mammals at low concentrations, but lethal to microorganisms such as bacteria. However, ozone, like any other strong oxidizing agent, can be harmful if not handled properly. Potential Health Effects as listed on the Ozone Material Safety Data Sheet (MSDS):

**INHALATION:** Ozone causes dryness of the mouth, coughing, and irritation of the nose, throat, and chest. It may cause labored breathing, headaches, and fatigue. However, the characteristic sharp, pungent odor is readily detectable at low concentrations (0.005 to 0.02 PPM).

**CORRECTIVE MEASURE:** Move to fresh air, loosen tight clothing around the torso; call medical attention if necessary; if breathing is difficult, a trained person/EMT should administer oxygen at 15 LPM via non-rebreather.

**SKIN:** Absorption through intact skin is not expected.

**CORRECTIVE MEASURE:** Wash skin thoroughly with soap and water.

**EYE CONTACT:** Ozone can be an irritant to the eyes causing minor inflammation.

**CORRECTIVE MEASURE:** Flush eyes with large amounts of water for at least 15 minutes while forcibly holding eyelids apart to ensure flushing of the entire eye surface. If irritation, pain, or other symptoms persist, seek professional medical attention.

**INGESTION:** It is not a route of exposure.

**AGGRAVATION OF PREEXISTING CONDITIONS:** Ozone may increase sensitivity to bronchiconstrictors including allergens, especially individuals with asthma.

**CHRONIC CONDITION:** Long term health effects are not expected from exposure to ozone. A partial tolerance appears to develop with repeated exposures.

**FOR SAFETY PROTECTION**, personal awareness of an odor of ozone should not be relied upon. Instrumentation and equipment should be provided to measure ambient ozone levels and perform the following safety functions:

- Initiate an alarm signal at an ambient ozone level of 0.1 PPM. Equipment may stay operational, if desired.
- Initiate a second alarm signal at ambient ozone levels of 0.3 PPM. This signal would also immediately shut down the ozone generation equipment. The majority of humans can smell ozone long before it is dangerous. The odor detection threshold is 0.005-0.02 PPM.

| OBSERVED EFFECTS | CONCENTRATION (PPM) |
|---|---|
| Threshold of odor, normal person | 0.005-0.02 |
| Maximum 8 hour average exposure limit | 0.1 |
| Minor eye, nose and throat irritation, headache, shortness of breath | >0.1 |
| Breathing disorders, reduced oxygen consumption, lung irritation, severe fatigue, chest pain, dry cough | 0.5-1.0 |
| Headache, respiratory irritation, and possible coma. Possibility of severe pneumonia at higher levels of exposure | 1-10 |
| Immediately dangerous to life and health | 10 |
| Lethal to small animals within two hours | 15-20 |

# THE HISTORY OF OZONE

Ozone was first discovered in the late 1700s. It was scientifically identified as a compound in 1840. Ten years later, the first Ozone Generator was built and by the end of the nineteenth century, ozone was in use as a drinking water treatment in the Netherlands.

**1785:** The odor of ozone was first reported by Van Mauren in the vicinity of an electrical discharge.

Christian Schonbein

**1840:** Christian Schonbein identifies ozone's characteristic odor, and names it after the Greek word " to smell."

**1857:** First industrial Ozone Generator built by Werner Von Slemans.

**1867:** Ozone's structure identified as triatomic oxygen.

**1893:** Ozone first commercialized as full-scale drinking water treatment at Oudshroom, The Netherlands.

**1903:** First U.S. municipal water installation at Niagara Falls, NY.

**1906:** Bon Voyage water plant built in Nice, France. Considered "the birthplace of ozone" for drinking.

**1909:** Ozone first used as a preservative for cold storage of meat.

**1914:** German Army applies ozone to battlefield wounds and infections.

1800 | 1850 | 1900 | 1950 | 2000

**1915:** German physician Albert Wolff uses ozone in the treatment of skin diseases.

**1932:** Dentist E.A. Fisch uses ozonated water as a disinfectant.

**1939:** Ozone found to prevent the growth of yeast and mold during storage of fruit.

**1950's:** Dr. W. Zable treats cancer using ozone.

**1970's:** Ozone first used in bottled water plants.

**1992:** First ozone delignification system starts up at Union Camp's Franklin, VA paper mill.

**1996:** USDA approves use of ozonated water for washing chicken carcasses.

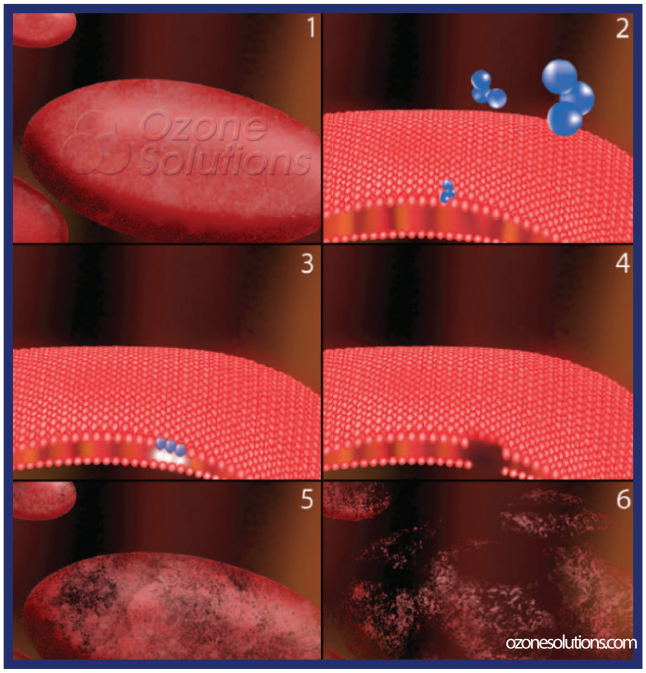
**2001:** FDA approves ozone as an antimicrobial agent for direct contact with food.

**2001:** USDA approves ozone for contact with meat and poultry.

Nice, France is often credited with the first municipal ozone installation. This is not the case. The first municipal ozone installation was at Oudshroom, Netherlands. However, it is no longer in operation. Nice, France is considered the birthplace of ozone because it is the oldest, continuously operating, ozone installation.

Source: BCC Research

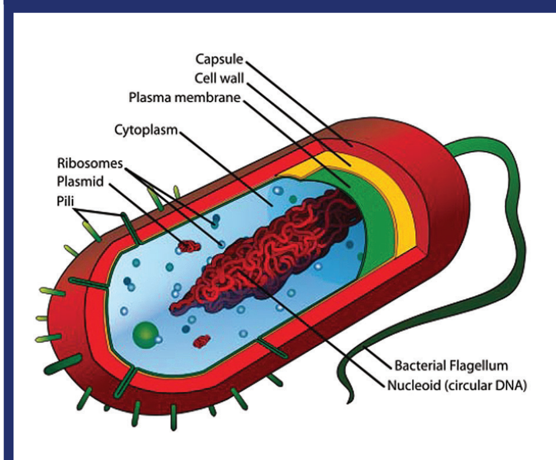
# OZONE EFFECTS ON BACTERIA, VIRUSES, & MOLDS




## HOW OZONE KILLS BACTERIA

1. A bacillus bacterial cell.
2. Ozone comes into contact with the cell wall. The cell wall is vital to the bacteria because it ensures the organism can maintain its shape.
3. As ozone molecules make contact with the cell wall, an oxidative burst occurs creating a tiny hole in the cell wall.
4. A newly created hole in the cell wall has injured the bacterium.
5. The bacterium begins to lose its shape while ozone molecules continue to create holes in the cell wall.
6. After thousands of ozone collisions over only a few seconds, the bacterial wall can no longer maintain its shape and the cell dies.
   - Bacteria cell oxidation via ozone contact typically occurs within 1-10 seconds!

Bacteriacelloxidationviaozonecontacttypically occurs within 1-10 seconds!




Thehumanbodyalsoprotectsitselfviaoxidativeburst! Whitebloodcellswillseekoutbacteriaintheblood stream. Thebacteriawillenvelopethewhitecell.Onceinsidethecell wall,thewhitecellwillmetabolizewaterintooxidantssuch ashydroxyl($OH^-$)andhydrogenperoxide($H_2O_2$).Thisaction destroysthecellfromtheinsideout.In2002,theScripps ResearchInstituteDepartmentofChemistryinLaJolla, CA,discoveredchemicalsignaturessimilartoozonewere present during oxidative burst.

Alwayshaveanozonemonitorpresentwhengeneratingozone.

You don't have to spend hundreds of dollars on an ozone monitor. Ozone badges exist for a great price!

Didyouknowthat,todate,therehasnotbeenasinglebacterium,virusorcystdiscoveredthatcanwithstandozone?Ozonekills them all!

- Ozone interferes with the metabolism of bacterium-cells, most likely through inhibiting and blocking the operation of the enzymatic control system. A sufficient amount of ozone breaks through the cell membrane, leading to the destruction of the bacteria.
- The effect of ozone below a certain concentration value is small or zero. Above this level all pathogens are eventually destroyed. This effect is called all-or-none response and the critical level the "threshold value."

| PATHOGEN | DOSAGE |
|---|---|
| Aspergillus Niger (Black Mount) | Destroyed by 1.5 to 2 mg/l |
| Bacillus Bacteria | Destroyed by 0.2 m/l within 30 seconds |
| Bacillus Anthracis | Ozone susceptible |
| Bacillus Cereus | 99% destruction after 5-min at 0.12 mg/l in water |
| B. Cereus (Spores) | 99% destruction after 5-min at 2.3 mg/l in water |
| Bacillus Subtilis | 90% reduction at 0.10-PPM for 33 minutes |
| Bacteriophage F2 | 99.99% destruction at 0.41 mg/l for 10-seconds in water |
| Botrytis Cinerea | 3.8 mg/l for 2 minutes |
| Candida Bacteria | Ozone susceptible |
| Clavibacter Michiganense | 99.99% destruction at 1.1 mg/l for 5 minutes |
| Cladosporium | 90% reduction at 0.10-PPM for 12.1 minutes |
| Clostridium Bacteria | Ozone susceptible |
| Clostridium Botulinum (Spores) | 0.4 to 0.5 mg/l threshold value |
| Coxsackie Virus A9 | 95% destruction at 0.035 mg/l for 10-seconds in water |
| Coxsackie Virus B5 | 99.99% destruction at 4.1 mg/l for 2.5-minutes in sludge effluent |
| Diphtheria Pathogen | Destroyed by 1.5 to 2 mg/l |
| Eberth Bacillus Typhus Abdomanalis) | Destroyed by 1.5 to 2 mg/l |
| Echo Virus 29: The virus most sensitive to ozone | After a contact time of 1 minute at 1 mg/l of ozone, 99.999% killed |
| Enteric Virus | 95% destruction at 4.1 mg/l for 29 minutes in raw wastewater |
| Escherichia Coli Bacteria (from feces) | Destroyed by 0.2 mg/l within 30 seconds in air |
| E-coli (in clean water) | 99.99% destruction at 0.25 mg/l for 1.6 minutes |
| Encephalomyocarditis Virus | Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l |
| Endamoebic Cysts Bacteria | Ozone susceptible |
| Enterovirus | Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l |
| Fusarium Oxysporium S Sp. Lycopersici | 1.1 mg/l for 10 minutes |
| Fusarium Oxysporium F Sp. Melonogea | 99.99% destruction at 1.1 mg/l for 20 minutes |
| GDVII Virus | Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l |
| Hepatitus A Virus | 99.5% reduction at 0.25 mg/l for 2-seconds in a phosphate buffer |
| Herpes Virus | Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l |
| Influenza Virus | 0.4 to 0.5 mg/l threshold value |
| Klebs-Loffler Bacillus | Destroyed by 1.5 to 2 mg/l |
| Legionella Pneumophila | 99.99% destruction at 0.32 mg/l for 20 minutes in distilled water |
| Luminescent Basidiomycetes | Destroyed in 10 minutes at 100-PPM |
| Mucor Piriformis | 3.8 mg/l for 2 minutes |
| Mycobacterium Avium | 99.9 with a CT value of 0.17 in water |
| Mycobacterium Foruitum | 90% destruction at 0.25 mg/l for 1.6 minutes in water |
| Penicillium Bacteria | Ozone susceptible |
| Phytophthora Parasitica | 3.8 mg/l for 2 minutes |
| Poliomyelitis Virus | 99.99% kill with 0.3 to 0.4 mg/l in 3-4 minutes |
| Poliovirus Type 1 | 99.5% destruction at 0.25 mg/l for 1.6 minutes in water |
| Proteus Bacteria | Very susceptible |
| Pseudomonas Bacteria | Very susceptible |
| Rhabdovirus Virus | Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l |
| Salmonella Bacteria | Very susceptible |
| Salmonella Typhimurium | 99.99% destruction at 0.25 mg/l for 1.67 minutes in water |
| Schistosoma Bacteria | Very susceptible |
| Staph Epidermidis | 90% reduction at 0.1-PPM for 1.7 minutes |
| Staphylococci | Destroyed by 1.5 to 2.0 mg/l |
| Stomatitis Virus | Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l |
| Streptococcus Bacteria | Destroyed by 0.2 mg/l within 30 seconds |
| Verticillium Dahliae | 99.99% destruction at 1.1 mg/l for 20 minutes |
| Vesicular Virus | Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l |
| Virbrio Cholera Bacteria | Very susceptible |
| Vicia Faba Progeny | OzonecauseschromosomeaberrationanditseffectistwicethatobservedbytheactionofX-rays |

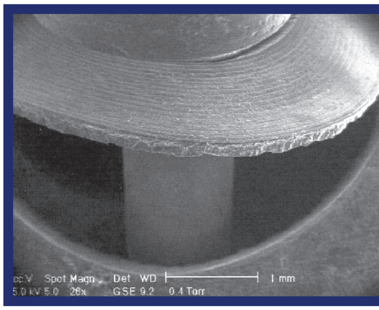
| KEY: | Bacteria | Virus | Mold |
|---|---|---|---|

# OZONE COMPATIBLE MATERIALS

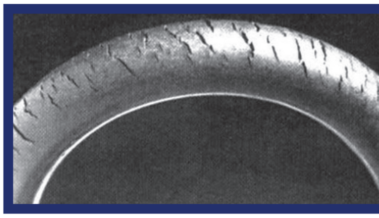
- Many of these materials were tested at the Ozone Solution's lab. Some are commonly known and rated as shown by others. All tests were performed at high levels (>1000 PPM) of ozone concentration.
- For any materials not shown, please call. We may have data on file or we can use our labs to test the material for you!

| MATERIAL | RATING |
|---|---|
| ABS plastic | B |
| Acetal (Delrin®) | C |
| Acrylic (Perspex®) | B |
| Aluminum | C (Wet Ozone)<br>B (Dry Ozone) |
| Brass | B |
| Bronze | B |
| Buna-N (Nitrate) | D |
| Butyl | A |
| Cast Iron | C |
| Chemraz | A |
| Copper | B |
| CPVC | A – Does get brittle |
| Cross-Linked Polyethylene (PEX) | A |
| Durachlor – 51 | A |
| EPDM | B (Dry Ozone)<br>C (Wet Ozone) |
| EPR | A |
| Ethylene-Propylene | A |
| Fiber Reinforced Plastics (FRD) | D |
| Flexelene | B |
| Fluorosilicone | A |
| Galvanized Steel | C |
| Glass | A |
| Hastelloy-C® | A |
| HDPE | A |
| Hypalon® | C |
| Hytrel | C |
| Inconel | A |
| Kalrez | A |
| Kel-F® (PCTFE) | A |
| LDPE | B |
| Magnesium | D |
| Monel | C |
| Natural Rubber | D |
| Neoprene | C |
| Nylon | D |
| PEEK | A |
| Polyacrylate | B |
| Polyamide (PA) | C |
| Polycarbonate | A |
| Polyethelyne | B |
| Polypropylene | C |
| Polysulfide | B |
| Polyurethane, Millable | A |
| PVC | A (Ozone in water) Does get brittle<br>B (Ozone in air) Does get brittle |
| PVDF (Kynar®) | A |
| Santoprene | A |
| Silicone | A |
| Stainless Steel – 304/316 | A |
| Stainless Steel – other grades | B |
| Steel (Mild) | D |
| PTFE | A |
| Titanium | A |
| Tygon | B |
| Vamac | A |
| Viton | A |
| Zinc | D |

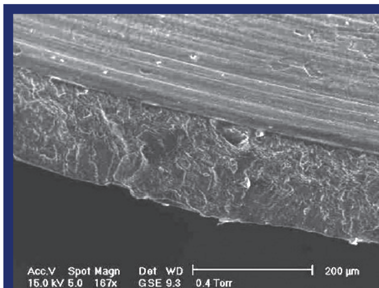
| RATING | | DESCRIPTION |
|---|---|---|
| A | Excellent | Ozone has no effect on these materials. They will last indefinitely. |
| B | Good | Ozone has minor effect on these materials. Prolonged use with high concentrations of ozone will break down or corrode these materials beyond usefulness. |
| C | Fair | Ozone will break down these materials within weeks of use. Prolonged use with any ozone concentration will break down or corrode these materials beyond usefulness. |
| D | Poor | Ozone will break down these materials within days or even hours of use. These materials are not recommended for any use with ozone. |



Electron microscope image of a nitrile butadiene rubber diaphragm seal after exposure to ozone. Note the cracks are formed at sharp corners in the seal.



Ozone cracking in natural rubber tubing.




Close-up of ozone cracking on nitrile butadine rubber, taken with an electron microscope.

EPDM is often listed as having an A rating or, no effect from ozone. This is not the case. Applying aqueous ozone to EPDM will result in small black streaks on your fingers when rubbed. This is a sign that ozone is breaking down the material. Do not use EPDM for water applications. Viton® is a superior alternative.

# FEEDGAS GENERATION

There are three types of feed gases used for ozone generation. They are ambient air, dry air, and concentrated oxygen. Each of these are described below along with their advantages and disadvantages.

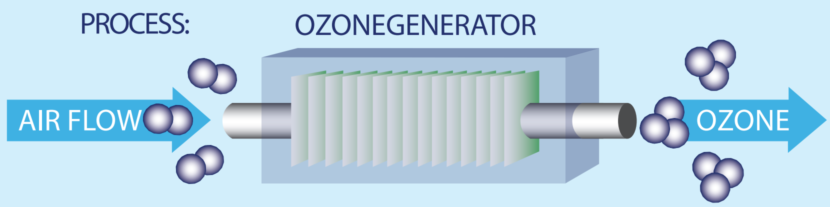
## 1 AMBIENT AIR – REFERS TO AIR FROM THE ENVIRONMENT, WHETHER IT IS LOCATED INDOORS OR OUTDOORS.

### ADVANTAGES

- Free
- Readily Available

### DISADVANTAGES

- Results in corona cell maintenance every few days, weeks, or months.
- Can cause electrical component problems due to insects that can get lodged in the corona or corona plate.




Using oxygen as a feedgas typically provides 2-3x the output of dry air and 4-6x the output of ambient air.

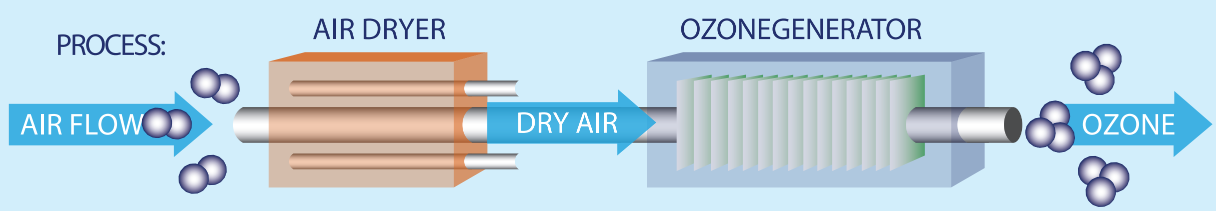
## 2 DRY AIR – REFERS TO AIR WHICH HAS MOISTURE REMOVED SO THE DEW POINT IS -60°C OR LOWER

### ADVANTAGES

- Allows a consistent ozone output over time
- Reduces corona cell maintenance (very important)
- All dust and insects are removed
- Associated equipment is less expensive than concentrated oxygen

### DISADVANTAGES

- Low concentrations result in low solubility in water
- More expensive than ambient air since equipment is required to remove moisture
- Still result in some nitric acid production
- Systems are more complex than using ambient air (need vacuum driven or pressure swing absorption air dryer)



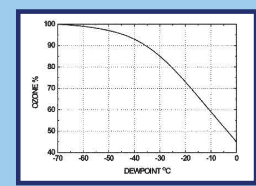




Chart shows how ozone generator output decreases as dewpoint (moisture content) increases. Left axis shows the relative output of the ozone generator. (e.g. At -10°C dewpoint, an ozone generator will be producing 60% of its maximum {rated} output).

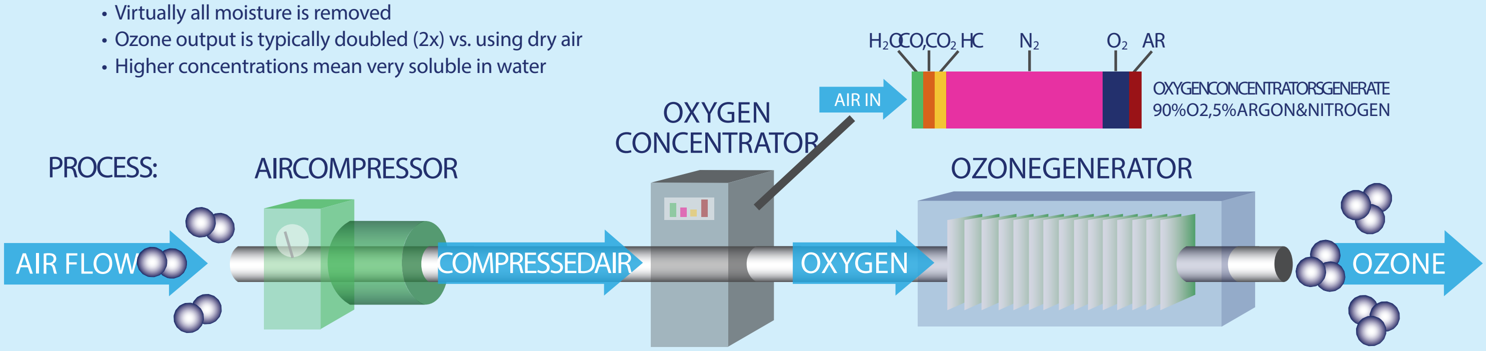
## 3 CONCENTRATED OXYGEN - REFERS TO OXYGEN WHICH IS OF MINIMUM 90% PURE WITH MOISTURE REMOVED -100°F DEWPOINT. IT CAN BE PRODUCED FROM AN OXYGEN CONCENTRATOR OR DELIVERED FROM AN OXYGEN CYLINDER.

### ADVANTAGES

- Allows a consistent ozone output over time
- Eliminates corona cell maintenance (very important)
- Virtually all moisture is removed
- Ozone output is typically doubled (2x) vs. using dry air
- Higher concentrations mean very soluble in water

### DISADVANTAGES

- More expensive than dry air systems since more equipment is required
- Systems are more complex than using dry air (need compressor and oxygen concentrator)



# OZONE TRANSFER VIA BUBBLE DIFFUSION

Ozone is a gas, therefore proper gas/liquid contact mechanisms are critical to efficient system design. Bubble diffusers are a popular, inexpensive method to inject ozone into water. The ozone gas transfer area occurs immediately at the interface between the ozone bubble surface and the surrounding water.

## BUBBLE DIFFUSION:

Diffusers permit ozone gas to pass through a porous membrane thus creating many small bubbles in the water, similar to a fish tank air stone. As the ozone bubble rises, the gas at the bubbles edge will transfer into the water. Using a diffuser requires enough pressure to overcome the height of the water and any restrictions in the diffuser due to hole size.

### ADVANTAGES

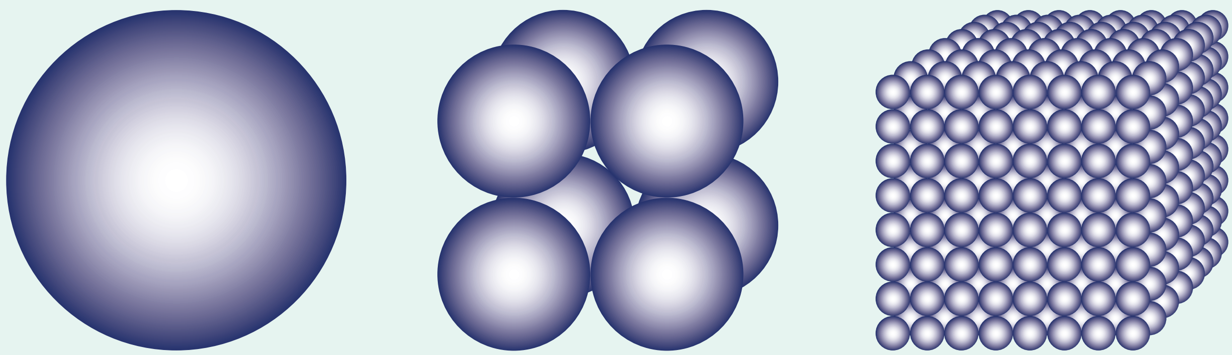
- Low cost
- Easy to set up
- Lowenergy–doesnotrequireawaterpump

### DISADVANTAGES

- Low mass transfer
- Highwatercolumns/vesselsaretypicallyrequired
- Difficult to use in pressurized water flows
- Diffuser pores can become plugged

- The diameter of a gas bubble has a dramatic impact on surface area
- Bepickywhenitcomestoselectingabubblediffuser.Itcanmeanthedifferencebetween success and failure.
- Thetransferofozonegasintowaterisdirectlyrelatedtoitssurfacearea(totalbubblesurface area)
- Itiscriticaltopreventthewaterfromback-flowingthroughthebubblediffuserandgoing intotheOzoneGenerator.Thebestmethodofpreventionistousemultiplecheckvalues(for redundancy) and a water trap.

## BUBBLE(S) VOLUME = 1 CUBIC FOOT



| 4.8 SQUARE FEET | 185 SQUARE FEET | 1,800 SQUARE FEET |
|---|---|---|
| 14.8 IN. DIAMETER | 10 MM DIAMETER | 1 MM DIAMETER |
| AREA = 1 | 38.5X AREA | 375X AREA |
| 1 BUBBLE | 54,000 BUBBLES | 54,000,000 BUBBLES |

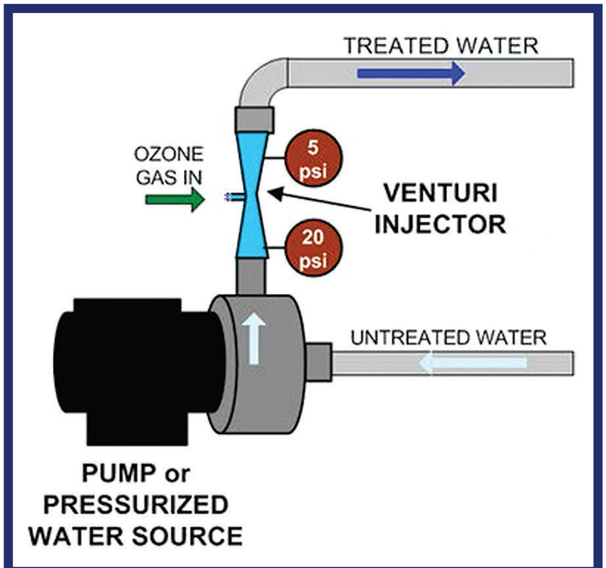
## CONCLUSION:SMALLERBUBBLESHAVEMUCHBETTEROZONEMASSTRANSFER!

Sources:(*"SupplementarySwimmingPoolTreatment'byPoolpakinternational.com–MK2_PTL_OZONE_Rev-20110527.pd.)
www.wastewater.com/techbulletins/117%20What%20is%20a%20Fine%20Fine@20Bubblex.pdf

! Want to know how many 0.5 mm bubbles it takes to contain 1 $ft^3$ of ozone? Find out on our ozone diffuser page. It will blow your mind!

# OZONE INJECTION VIA VENTURI

A more popular method for delivering ozone is through the use of Venturi Injectors. Venturi Injectors work by forcing water through a conical body. This action creates a pressure differential between the inlet and outlet ports, which results in a vacuum inside the injector body. This vacuum causes rapid ozone suction through the suction port.




Venturis require a constant pressure differential to initiate ozone injection. (15 PSI in this example).

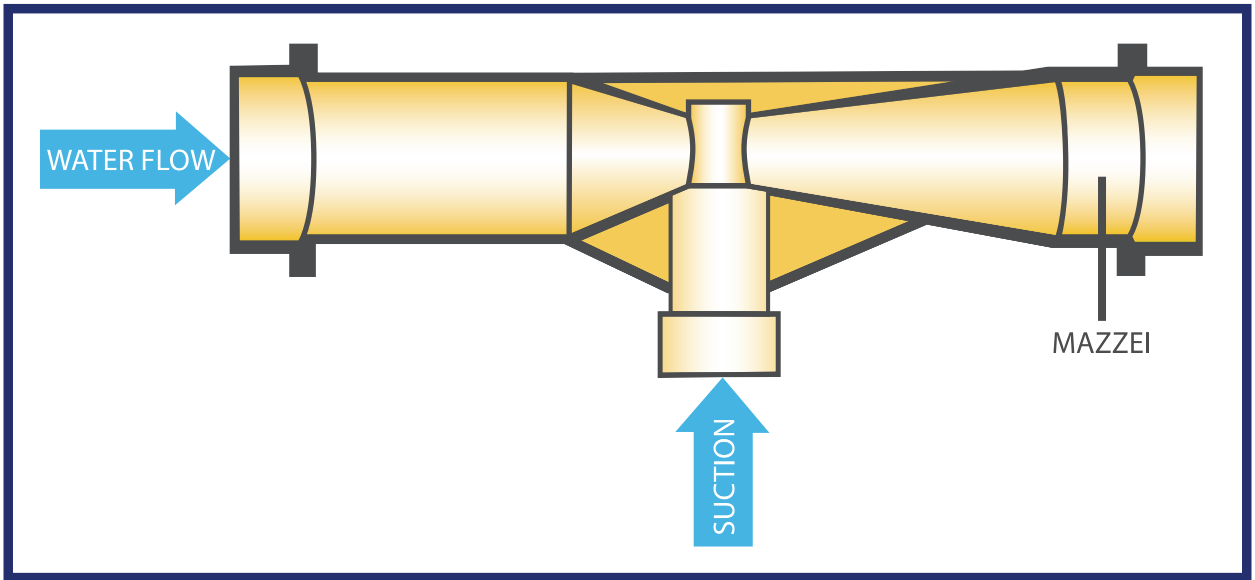
## ADVANTAGES

- Mass transfer efficiencies up to 98%*
- Works well in pressurized streams
- Minimal maintenance required
- More controlled and consistent over time

## DISADVANTAGES

- Requires energy from a booster pump or pressurized water supply

Tiny air bubbles (white) can be seen mixed with the water.




Water, moving from left to right through a conical body creates suction which pulls air/ozone into the water stream

A very high liquid to gas ratio is required to achieve 98% mass transfer efficiency. In fact, the ratio required would not be economical. Typical mass transfer efficiencies for Venturi range from 50-70% (without the use of pressure).

# OZONESOLUBILITYINWATER

- Solubility is the property of a solid, liquid, or gaseous chemical substance called solute to dissolve in a solid, liquid, or gaseous solvent.
- One gas is oxygen or $O_2$. We breathe it every day, but so do fish who live under water. This means that $O_2$ is soluble with the water. Ozone gas ($O_3$) is 13 times more soluble in water than $O_2$ gas!

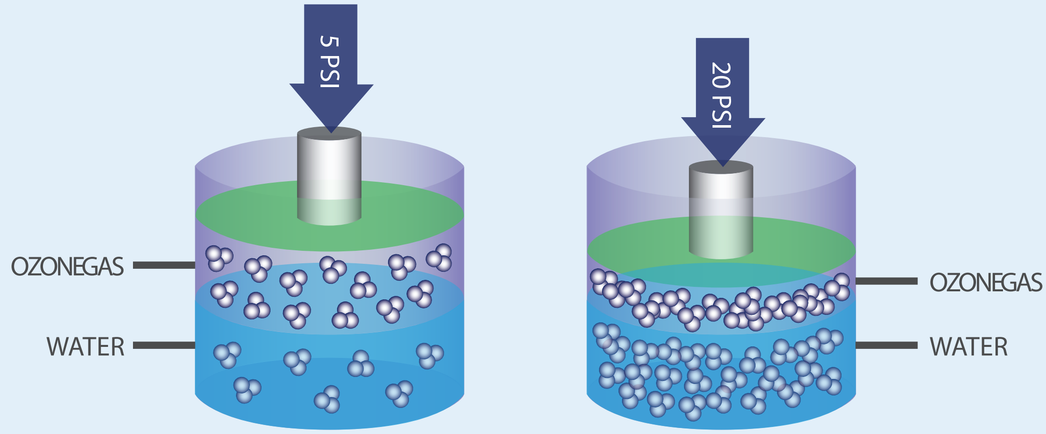
## WATER TEMPERATURE AND SOLUBILITY

Water at 86°F will have less ozone bubbles than water at 50°F.

Water at 50°F will have more ozone bubbles than water at 86°F.

## CONDITIONS WHICH EFFECT THE SOLUBILITY LEVEL OF A GAS INTO WATER

- One is the temperature of the water.
- Another factor is water pressure. At a higher pressure, more ozone will be dissolved into the water.
- Pressurized gas, meaning gas that is at an increased pressure, being applied into the water, which is also under an increased pressure, will increase the solubility.
- If the gas that you are placing into the water is at an increased pressure, this will allow additional solubility. This means a higher mass transfer of ozone into water.




## CONCLUSION:HIGHERWATERPRESSURESRESULTINHIGHERDISSOLVEDOZONELEVELS

Addinganyoneoftheabovelisttoyourprocesswillimprovethesolubility.Incorporatingmorethanonewillbeevenbetter.

# OZONE FORMULAS

Here is the formula for determining the actual flow rate of a gas under pressure inside a flowmeter.

## ADJUST FLOW RATE CONVERSION

$$\text{(ADJUSTEDFLOW)} = \text{(MEASUREDFLOW)} \bullet \sqrt{\frac{\text{(OXYGENPRESSURE)} + 14.7}{14.7}}$$

## CALCULATE OZONE DOSAGE IN WATER

- The formula is actually very simple.
- It is **water flowrate x ozone dosage = required ozone production.**

UNITS CONSISTENCY IS VERY IMPORTANT.

- Blow is the formula for determining ozone generation requirements if you know common water and ozone parameters (**flowrate** in GPM and **ozone dosage** in mg/l).

FLOWRATE (GPM x 3.75 l/gal x 60 min/hr x ozone dosage (mg/l) = ozone production (mg/hr).

- Let's work through an example. How much ozone production is needed to dose 2 PPM into 20 GPM of water? (We will be using PPM throughout the rest of this example knowing that 1 mg/l = 1 PPM).

20 GPM x 3.75 l/gal x 60 min/hr x 2 PPM = 9084 mg/hr (9g/hr).

- Remember that 9 g/hr will permit one to dose the water with 2 PPM of ozone. This does not mean that 2 PPM will be the final dissolved ozone concentration. Due to efficiency losses with injecting ozone and ozone demand of the water, the dissolved ozone concentration will be less.

## CALCULATE THE OUTPUT OF AN OZONE GENERATOR

- The formula is **flowrate (lpm) x ozone concentration (g/m3) = ozone production (mg/hr).**
- Let's work through another example: The ozone concentration exiting an Ozone Generator is 120 g/m3 at 5 lpm of oxygen flow. What is the output?

5 l/min x 120 g/m$^3$ x (1 m$^3$/1,000 l) = 0.60 g/min.

- g/min are not common units so we simply convert minutes to hours to get g/hr: 0.60 g/min x 60 min/hr = **36 g/hr.**

## SAMPLE CONVERSIONS

- Convert 140 g/m$^3$ to wt% (oxygen feedgas)
- 100 g/m$^3$ is equivalent to 6.99 wt%
- Therefore 140 g/m$^3$ / 100 g/m$^3$ x 6.99 wt% = **9.8 wt%**

Did you know that managers of hog confinements have reported reductions in fly populations when ozone is used in the gaseous form?

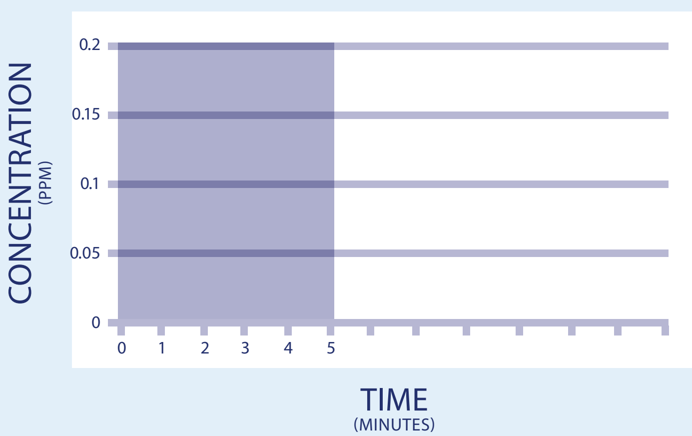
!

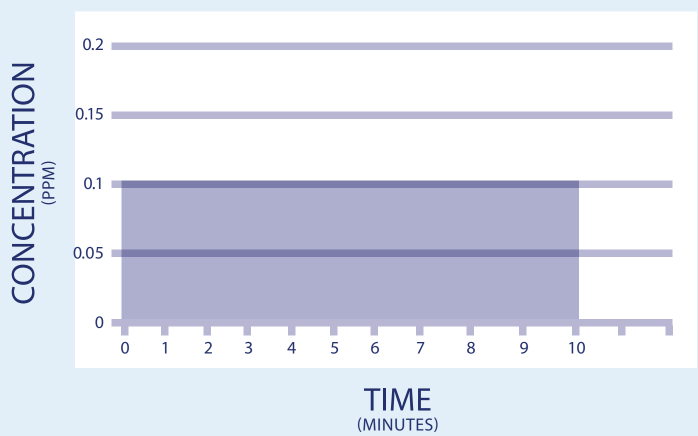
# CT VALUE - WHAT IS IT?

## CT VALUE DEFINED

- "CT" is the product of "residual disinfectant concentration" (C) in mg/l, and the corresponding "disinfectant contact time" (T) in minutes. In other words, for ozone CT, it is the dissolved ozone concentration multiplied by the contact time. (remember that 1 mg/l = 1 PPM)
- Some sanitizing treatments with ozone can be accomplished very quickly, but some treatments will require sufficient ozone in the water along with an adequate contact time. This contact time is required for the dissolved ozone to oxidize organic contaminants **and** to disinfect the water.
- This CT value is assumed to be unit-less. Either the ***Concentration*** can be held constant while the ***Time*** is varied, or visa-versa, to assure a given level of disinfection is obtained.
- For example, a CT value the bottled water industry uses is 1.6. This means the dosage rate is 1.6 mg/l minutes. The operator has a choice of ozonating at 0.2 PPM for 8 minutes or 0.4 PPM for 6 minutes. It is up to them as long as the final CT is 1.6.

HERE'S HOW IT WORKS OUT:




BOTH CHARTS PRESENT A CT VALUE OF 1.0, CONCENTRATION (PPM) X TIME (MINUTES).

Youmayhaveheardtheclaim,"ozoneis3,000xmoregermicidalthanChlorine."Whatdoesthismean?Thisstatementhinges onthefactthatforsomeorganisms,youneedaCTvalue3,000xhigherwhenusingchlorinevs.ozone.Putanotherway,ifa dissolvedozonelevelof0.2PPMfor1minute(CTis0.2)isneededtoinactivateaspecificmicroorganism,youwillneed200PPM of chlorine for 3 minutes (CT = 600) to achieve the same kill effect.

# OZONE CONVERSIONS

## PHYSICAL PROPERTIES, STANDARD CONDITIONS; P=1013.25MB, T=273.3K

- Density of ozone: 2.14 $kg^3$
- Molecular weight of ozone: 48
- Density of oxygen: 1.43 $kg/m^3$
- Molecular weight of oxygen: 32
- Density of air: 1.29 $kg/m^3$
- Density of water: 1,000 $kg/m^3$

## USEFUL CONVERSION FACTORS: (FOR WATER)

- 1,000 liters = 1 $m^3$ = 264 US gallons = 35.5 $ft^3$
- 1 gal = 3.785 liters = 3,785 ml

## OZONE CONCENTRATION IN WATER

- 1 mg/l = 1 PPM = 1 $g/m^3$ water (By weight)

## OZONE CONCENTRATION IN AIR BY VOLUME

- 1 $g/m^3$ = 467 PPM
- 1 PPM = 2.14 $mg/m^3$

## OZONE CONCENTRATION IN AIR BY WEIGHT

- 100 $g/m^3$ = 6.99% (Approximate)
- 1% = 14.3 $g/m^3$ (Approximate)
- 1% = 6,520 PPM

## OZONE CONCENTRATION IN OXYGEN BY WEIGHT

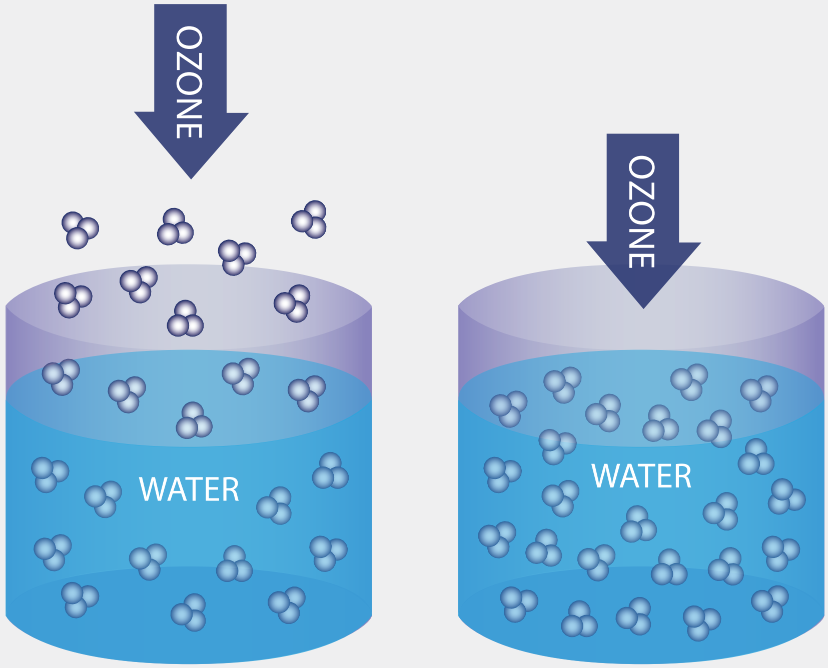
- 100 $g/m^3$ = 6.99% (Approximate)
- 1% = 14.3 $g/m^3$ (Approximate)
- 1% = 6,520 PPM

Did you know that in semiconductor applications it takes an estimated 1,500-3,000 gallons of water to make a single 12-in wafer? (3,000 gallons is the approximate volume inside a 15-passenger van). ?

One part per million is equivalent to one blue golf ball in a room 18-ft x 18-ft x 8-ft high filled with white golf balls! !

# OZONE DOSAGE VS. DISSOLVED OZONE

- The quantity of ozone applied to the water will always exceed the amount of ozone actually absorbed into solution.
- Often times, due to system inefficiencies, a portion of the ozone off-gases without being absorbed into the water. This wasted ozone must then be vented outside or destroyed with an ozone destruct unit.




OZONE DOSAGE: THE AMOUNT OF OZONE APPLIED TO THE WATER

DISSOLVED DOSAGE: THE AMOUNT OF OZONE MEASURED IN THE WATER

### WHAT ARE THE UNITS OF DISSOLVED OZONE?

The units are PPM or mg/l. They are equivalent with a 1:1 ratio.

### WHAT ARE THE UNITS OF OZONE DOSAGE?

The units are also PPM or mg/l. But how can this be, if ozone has not actually been dissolved into solution?

Remember that PPM is a ratio. 1 PPM is one part ozone for every 1,000,000 parts (molecules) of water. An operator will know the quantity of ozone being produced. They will also know the quantity of water passing through a Venturi (the typical method of injecting ozone). The ratio of generated gas to moving liquid will give us a value which can be expressed in PPM (or mg/l).


Dissolved Ozone Monitor

You might see an Ozone System parameter which states 2.0 PPM ozone dosage. Do not confuse this with dissolved ozone. 2 PPM ozone dosage will often times translate into 1 PPM, or less, dissolved ozone due to losses.

! The amount of ozone that you place into the water will not remain that same value. The dissolved ozone will be reduced by the water conditions, such as the temperature, organic pathogens, etc. To obtain the desired dissolved ozone level, you must add ozone until you overcome the contaminants and the other ozone diminishing conditions.

Did you know that there are a few Ozone Injection Systems that can exceed 90% mass transfer efficiency in clean water? They utilize pressure and high ozone concentrations.

# OZONE FALLACIES

We have heard them all. Now it is time we set the record straight. Below is a list of a few ozone fallacies we have heard over the years.

## "OZONE WILL OXIDIZE MY METAL PIPES."

This claim conjures an image of ozonated water running through pipes and when you come in the next morning, they are rusted through. This is not the case. The pH level has more effect on corrosion rates of metals than most industry accepted dissolved ozone levels. While a powerful oxidizer, ozone has minimal effect on corrosion rates. Iron pipes that carry ozone gas, while not recommended, will last for months, or years, before any noticeable corrosion is present. For ozonated water, iron pipes will oxidize faster than water with just oxygen, but the pipes can last for years before needing replacement.

**Ozone Solutions recommends the use of ozone approved materials. Iron pipes are not ideal but they will not degrade within a few days or even weeks as most people would have you believe. The same is true for most rubber seals.**

## "THE SKY IS BLUE BECAUSE OF OZONE."

Okay, this one is not related to our business, but we have heard it mentioned before so we will address it. While ozone is a blue gas, the sky is blue for a very different reason.

The blue color of the sky is due to Rayleigh scattering. Blue light has a shorter wavelength than the other "rainbow colors." This blue light is absorbed by the gas molecules. The absorbed blue light is then radiated in different directions. It gets scattered all around the sky. Whichever direction you look, some of this scattered blue light reaches you. Since you see the blue light from everywhere overhead, the sky looks blue.

**So the next time your kid asks "Why is the sky blue?" you will have the answer!**

## "OZONE DOES NOT HAVE ANY RESIDUAL."

**This one is also false, but clarification is needed. Ozone has an extremely short half-life. This short half-life makes it very reactive and excellent at killing pathogens. In very clean water, ozone can last for several hours*. In most food processing applications, ozone half-life is anywhere from 10-20 minutes. For wastewater applications, the ozone residual is dependent on the organic loading with high organic loading resulting in short ozone half-life.**

In 2003, Manassis Mitrakas reported that ozone can remain in a bottle up to 6 hours with an ozone dose of 0.10 PPM!*

*Manassis Mitrakas, Athanasios Patsos, et al, "Effect of Temperature on CT value and Bromate Formation During Ozonation of Bottled Water" Fresenius Environmental Bulletin; 2008 Vol 17 Numb 3, pgs 341-346

# FDA&USDAPERMITOZONEUSEONFOOD

## CAN OZONE BE USED ON FOOD?

### YES IT CAN!

**See official directives below.**

***Ozone has been given GRAS approval by the USDA and the FDA for direct contact with food products, including all meat and poultry products.*** While good manufacturing procedures must be in place, no regulations exist on levels of ozone in food processing applications. The final rule from the FDA providing GRAS approval was given in 2001. The USDA followed with the final rule granting GRAS approval for ozone in 2002. References for all these actions, along with the specific rules, are provided below.

OzonehasbeengivenGRASapprovalbytheUSDA andtheFDAfordirectcontactwithfoodproducts, including all meat and poultry products.

### REGULATIONS

***USDA final rule on ozone dated 12/17/2002, FSIS Directive 7120.1 States:*** Ozone can be used on all meat and poultry products. Ozone can be used in accordance with current industry standards of good manufacturing practice. No other guidelines are given on levels or dosages of ozone.

USDA Guidance on Ingredients and sources of radiation used to reduce microorganisms on carcasses, ground beef, and beef trimmings: Ozone is classified as a Secondary direct food additive/processing aid allowable for all meat and poultry products.

***FDA Federal Register Vol. 66 No. 123***

The Food and Drug Administration (FDA) is amending the food additive regulations to provide for the safe use of ozone in gaseous and aqueous phases as an antimicrobial agent on food, including meat and poultry. This action is in response to a petition filed for the Electric Power Research Institute, Agriculture and Food Technology Alliance.

ThisruleiseffectiveJune26,2001.

### USDA Reference 21 CFR 173.368

Ozone(CASReg.No.10028—15—6)maybesafelyusedinthetreatment,storage,andprocessingoffoods,includingmeatandpoultry(unlesssuchuseisprecludedbystandardsof identityin9CFRpart319),inaccordancewiththefollowingprescribedconditions:(a)Theadditiveisanunstable,colorlessgaswithapungent,characteristicodor,whichoccursfreelyin nature.Itisproducedcommerciallybypassingelectricaldischargesorionizingradiationthroughairoroxygen.(b)Theadditiveisusedasanantimicrobialagentasdefinedin§170.3(o)(2)ofthischapter.(c)TheadditivemeetsthespecificationsforozoneintheFoodChemicalsCodex,4thed.(1996),p.227,whichisincorporatedbyreference.TheDirectoroftheOfficeofthe FederalRegisterapprovesthisincorporationbyreferenceinaccordancewith5U.S.C.552(a)and1CFRpart51.CopiesareavailablefromtheNationalAcademyPress,2101ConstitutionAve. NW.,Washington,DC20055,ormaybeexaminedattheOfficeofPremarketApproval(HFS—200),CenterforFoodSafetyandAppliedNutrition,FoodandDrugAdministration,200CSt. SW.,Washington,DC,andtheOfficeoftheFederalRegister,800NorthCapitolSt.NW.,suite700,Washington,DC.(d)Theadditiveisusedincontactwithfood,includingmeatandpoultry (unlesssuchuseisprecludedbystandardsofidentityin9CFRpart319or9CFRpart381,subpartP),inthegaseousoraqueousphaseinaccordancewithcurrentindustrystandardsofgood manufacturingpractice.(e)Whenusedonrawagriculturalcommodities,theuseisconsistentwithsection201(q)(1)(B(i)oftheFederalFood,Drug,andCosmeticAct(theact)andnotapplied for use under section 201(q)(1)(B)(i)(I), (q)(1)(B)(i)(II), or (q)(1)(B)(i)(III) of the act.

# SAFETY DATA SHEET (FORMERLY MSDS)

## 1. PRODUCT IDENTIFICATION

**Product Name: OZONE**

**Common Names/Synonyms:** Triatomic Oxygen, Trioxygen

**Ozone Generator Manufacturer/Supplier**
Ozone Solutions, Inc. www.ozonesolutions.com
451 Black Forest Rd. info@ozonesolutions.com
Hull, IA 51239
712-439-6880

**Product Use:** This SDS is limited to ozone produced in gaseous form on site by an ozone generator, in varying concentrations, in either air or aqueous solution, for the purposes of odor abatement, oxidation of organic compounds, or antimicrobial intervention, in a variety of applications.

## 2. HAZARD IDENTIFICATION

GHS Classifications:

| Physical: | Health: | Environmental: |
|---|---|---|
| Oxidizing Gas | Skin Irritation – Category 3<br>Eye Irritation – Category 2B<br>Respiratory System Toxicity – Category 1 (Single & Repeated) | Acute Aquatic Toxicity – Category I |

NOTE: Severe respiratory toxicity will develop before skin or eye irritation go beyond listed categories. ***Anyone with chronic pulmonary problems, especially asthma, should avoid exposure to ozone.***

WHMIS Classifications (Workplace Hazardous Materials Information System, Canada): **C, D1A, D2A, D2B, F**
Source: CCOHS CHEMINFO Record Number 774

## 3. COMPOSITION

| | |
|---|---|
| Chemical name: | Ozone |
| Common names: | Triatomic oxygen, trioxygen |
| Chemical Formula: | $O_3$ |
| CAS Registry Number: | 10028-15-6 |

## 4. FIRST AID MEASURES

| Route of Entry | | Symptoms | First Aid |
|---|---|---|---|
| Skin Contact | YES | Irritation | Rinse with water |
| Skin Absorption | NO | NA | NA |
| Eye Contact | YES | Irritation | Rinse with water, remove contacts |
| Ingestion | NO | NA | NA |
| Inhalation | YES | Headache, cough, heavy chest, shortness of breath | Remove to fresh air, provide oxygen therapy as needed |

For severe cases, or if symptoms don't improve, seek medical help.

## 5. FIRE FIGHTING MEASURES

Ozone itself is not flammable. As a strong oxidant it may accelerate, even initiate, combustion, or cause explosions. Use whatever extinguishing agents are indicated for the burning materials.

## 6. ACCIDENTAL RELEASE MEASURES

Turn off the ozone generator, and ventilate the area. Evacuate until ozone levels subside to a safe level (<0.1 ppm).

## 7. HANDLING AND STORAGE

Ozone must be contained within ozone-resistant tubing and pipes from the generation point to the application point.

## 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

OSHA Permissible Exposure Limit: 8 hour TWA **0.1 ppm**

ANSI/ASTM: 8 hour TWA **0.1 ppm**, STEL **0.3 ppm**

ACGIH: 8 hour TWA **0.1 ppm**; STEL **0.3 ppm**

NIOSH: ELCV **0.1 ppm** light; **0.08 ppm** moderate; **0.05 ppm**, heavy
Light, moderate, heavy work TWA <= 2 hours: **0.2 ppm**
Immediately Dangerous to Life or Health (IDLH) **5 ppm**

**Respiratory Protection**: Use full face self-contained breathing apparatus for entering areas with a high concentration of ozone.

**Engineering control**: Use ozone destruct unit for off gassing of ozone.

## 9. PHYSICAL AND CHEMICAL PROPERTIES

| | | | |
|---|---|---|---|
| Physical state | Gas | pH | NA |
| Molecular Weight | 48.0 | Decomposition temperature | NA |
| Appearance | Clear at low concentration, blue at higher concentration | Evaporation rate | NA |
| Odor | Distinct pungent odor | Flash point | NA |
| Odor threshold | 0.02 to 0.05 ppm; exposure desensitizes | Auto-ignition temperature | NA |
| Melting point | -193°C/-315°F | Relative density | NA |
| Boiling point | -193°C/-315°F | Partition coefficient | NA |
| Vapor pressure | > 1 atm | Flammability | NA |
| Vapor density | 1.6 (air = 1) | Explosive limits | NA |
| Solubility in water | 570 mg/L @20°C & 100% $O_3$; 0.64 @0°C | Viscosity | NA |

## 10. STABILITY AND REACTIVITY

Ozone is highly unstable and highly reactive. Avoid contact with oxidizable substances. Ozone will readily react and spontaneously decompose under normal ambient temperatures.

## 11. TOXICOLOGICAL INFORMATION

Likely routes of exposure: inhalation, eyes, skin exposure.

Effects of Acute Exposure: Discomfort, including headache, coughing, dry throat, shortness of breath, pulmonary edema; higher levels of exposure intensify symptoms. Possible irritation of skin and/or eyes.

Effects of Chronic Exposure: Similar to acute exposure effects, with possible development of chronic breathing disorders, including asthma.

LC50: mice, 12.6 ppm for 3 hours; hamsters, 35.5 ppm for 3 hours

| | |
|---|---|
| Irritancy of Ozone | YES |
| Sensitization to Ozone | NO |
| Carcinogenicity (NTP, IARC, OSHA) | NO |
| Reproductive Toxicity, Teratogenicity, Mutagenicity | Not Proven |
| Toxicologically Synergistic Products | Increased susceptibility to allergens, pathogens, irritants |

## 12. ECOLOGICAL INFORMATION

The immediate surrounding area may be adversely affected by an ozone release, particularly plant life. Discharge of ozone in water solution may be harmful to aquatic life. Due to natural decomposition, bioaccumulation will not occur, and the area affected will be limited.

## 13. DISPOSAL CONSIDERATIONS

Off-gassing of ozone should be through an ozone destruct unit which breaks ozone down to oxygen before release into the atmosphere.

## 14. TRANSPORT INFORMATION

NOT APPLICABLE, as ozone is unstable and either reacts or decomposes, and must be generated at the location and time of use.

## 15. REGULATORY INFORMATION

SARA Title III Section 302 EHS TPQ: 100 lbs.

SARA Title III Section 304, EHS RQ: 100 lbs.

SARA Title III Section 313: > 10,000 lbs. used/year.

Source: EPA List of Lists

## 16. OTHER INFORMATION

Half-life of ozone in water at 20°C = 20 min; in dry still air at 24°C = 25 hr; decreases significantly with increase in humidity, presence of contaminants, air movement, and/or increase in temperature.

APPLICATIONS

## APPLICATIONS & INDUSTRIES

- Air Treatment & Odor Control
- Aquaculture & Zoos
- Biofuel
- Bottled Water
- CIP (Clean in Place)
- Cooling Tower
- Dairy
- Drinking Water Treatment
- Food Processing & Storage
- Grain & Feed Remediation
- Groundwater & Soil Remediation
- HVAC
- Laundry
- Livestock
- Medical
- Pharmaceutical
- Pools, Waterparks, & Spas
- Pulp & Paper
- Semiconductor Production
- Wastewater Treatment
- Wine & Beer

CONTACT

## CONTACT US FOR MORE INFORMATION

OZONE SOLUTIONS
The element of success.

Ozone Solutions, Inc.
451 Black Forest Road • Hull, IA 51239
Tel: 1.712.439.6880 | Fax: 1.712.439.6733

Visit us on the web:
www.ozonesolutions.com

Email us:
info@ozonesolutions.com
sales@ozonesolutions.com