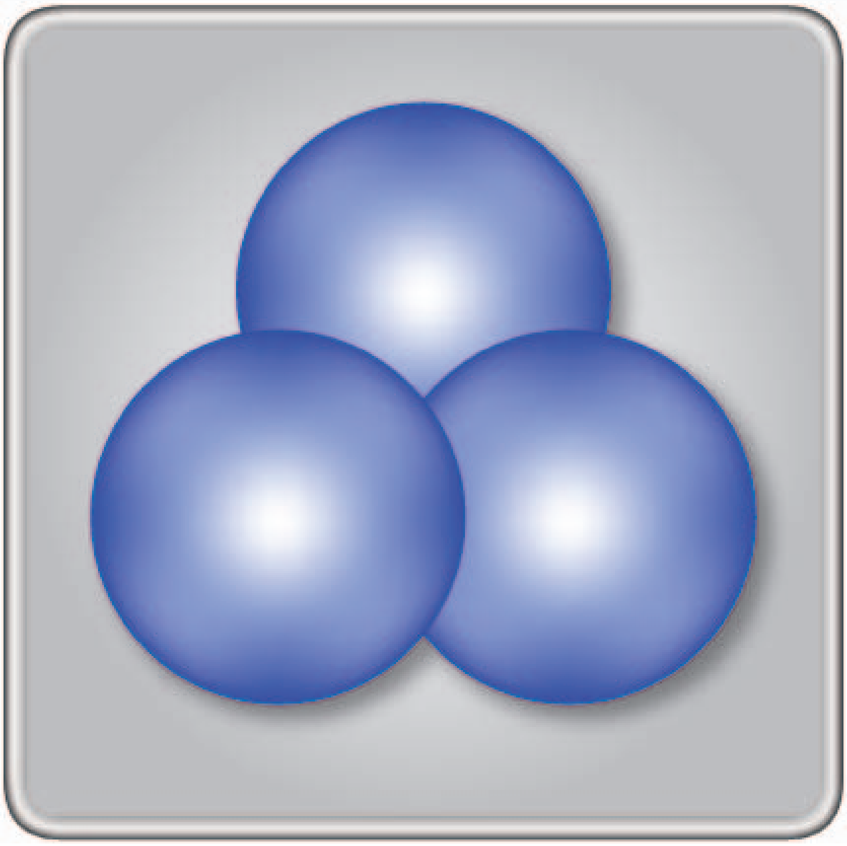
The Definitive Guide to Understanding Ozone



The good, bad, and ugly of ozone.

Ozone Solutions

You are reading the ***first ever*** online ozone guide. We've 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!

— 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 worldview".

— Indicates tips for good Ozone System design.

— All pages have a QR code that will bring you directly to that webpage.

If you find an incorrect fact in this guide, please email me at scott@ozonesolutions.com

Sincerely,
Scott Postma
General Manager
Ozone Solutions, Inc.

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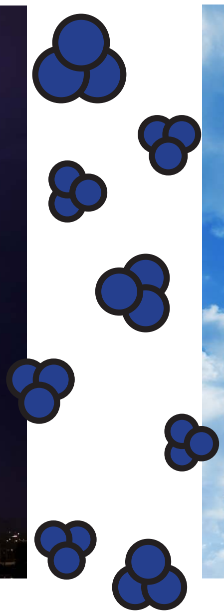
Properties of Ozone vs. Oxygen

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	—
Identifying Smell	• Clothes after being outside on clothesline • Photocopy machines • Smell after lightning storms	Odorless
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
Hazardous Decomposition	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 of 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 breath at these high altitudes. You didn't think that you kept breathing the same air over and over, did you?

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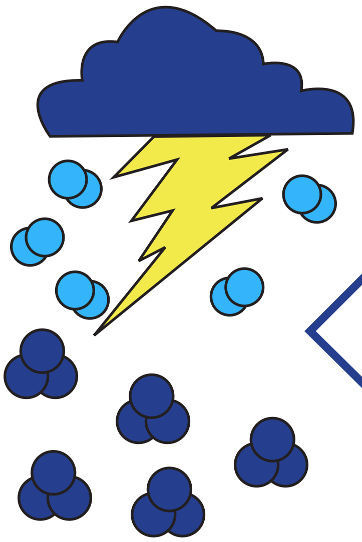
Click for more information on the ***properties of ozone***.

How is Ozone Made?

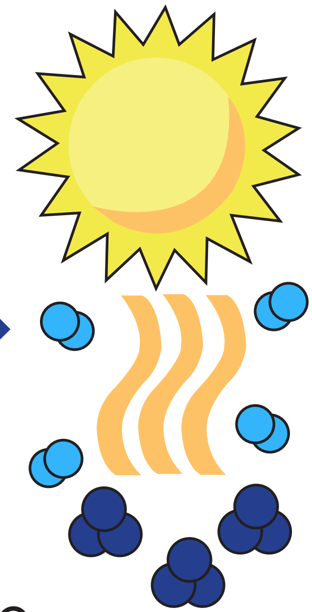
Did you know that ozone is made in nature?

It naturally does it in two ways.

Lightning
(corona discharge)



UV Light
(sun)



1. Lightning passing through the air creates ozone from oxygen.

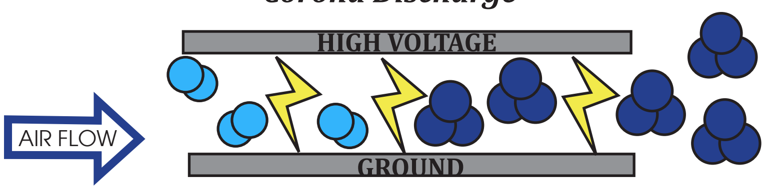
2. Oxygen in the presence of 185 nm UV light creates ozone.

Both methods break-up oxygen molecules to form ozone.

How do we make ozone?

Same methods as above but on a much smaller scale.

Corona Discharge

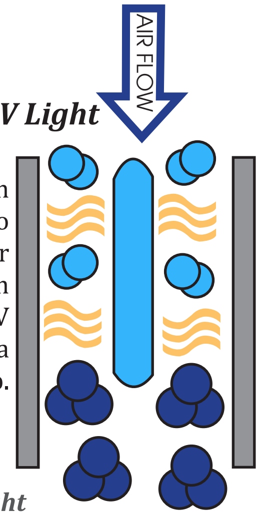


Oxygen, from the air, is forced between high voltage plates to simulate corona discharge. The oxygen is broken apart and recombines into ozone.

Advantages of Corona Discharge

- Generates high ozone concentrations
- Best for water applications
- Fast organic (odor) removal
- Consistent ozone output

UV Light



Oxygen turns into ozone after it is hit with 185 nm UV light from a UV bulb.

Advantages of UV Light

- Simple construction
- Lower cost than corona discharge
- Output less affected by humidity

Did you know that a single lighting strike can create over 300-lbs of ozone? Want to see the ozone calculation?

The first patent for an Ozone Generator was by Nikola Tesla in 1896. Click to see the very ***first Ozone Generator patent***.

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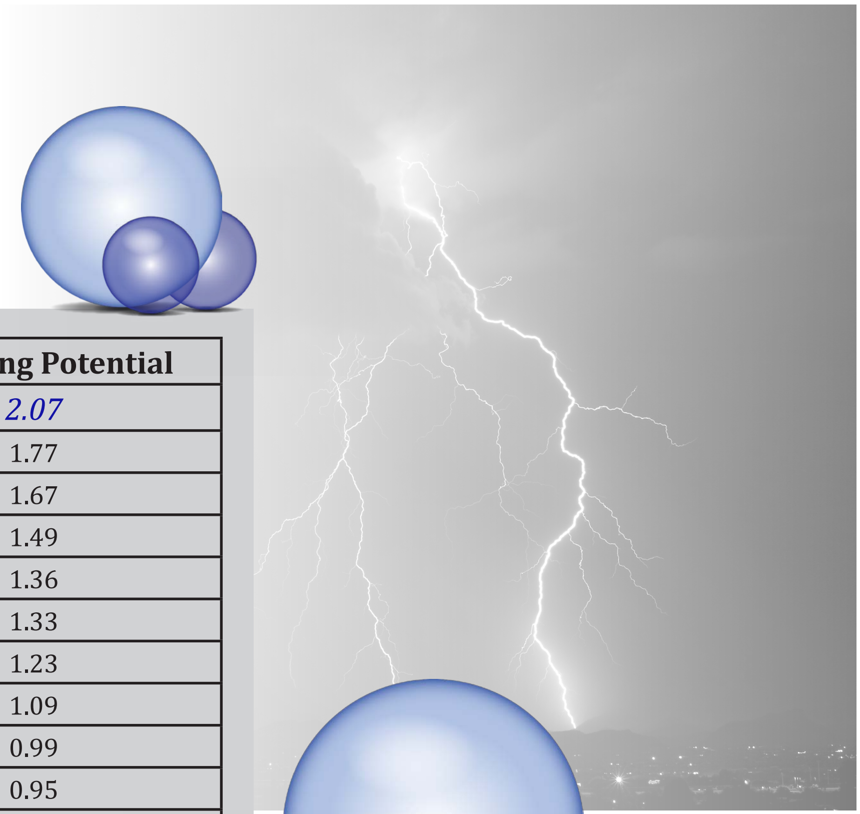
Click to learn more about how ***ozone formation***.

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 oxidant 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 thereby improving filtration
- Ozone can be effective in partially oxidizing organics in the water to biodegradable compounds that can be removed by biological filtration



Oxidizing Regent	Oxidizing Potential
Ozone	*2.07*
Hydrogen Peroxice	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/sdwa/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 were 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.***

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Click to learn more about the ***advantages of ozone***.

Negatives of Ozone

Like every oxidant, ozone has its down-sides. 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 similiar "negative" effect as ozone if used improperly. Proper implementation is key to achieving outstanding results in your process.

<u>The real negatives are listed below</u>:

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, but 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)		
Temperature		Time
F°	C°	
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 Pre-existing Conditions: Ozone may increase sensitivity to bronchia constrictors 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.

You don't have to spend hundreds of dollars on an ozone monitor. Ozone badges exist for only $10!

Always have an ozone monitor present when generating ozone.

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:

1. Initiate an alarm signal at an ambient ozone level of 0.1 PPM. Equipment can stay operational, if desired.
2. 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 hr. average exposure limit	0.1
Minor eye, nose, and throat irriation, 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 sever pneumonia at higher levels of exposure	1-10
Immediately dangerous to life and health	10
Lethal to small animals within two hours	15-20

Click to learn of how many documented ozone deaths have occurred in the last century.

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Click to learn more about ***ozone safety and regulation***.

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 drinking water treatment in the Netherlands.

Christian Schonbein

- 1785 – The odor of ozone was first reported by Van Mauren in the vicinity of an electrical discharge
- 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 in full-scale drinking water treatment at Oudshroom, The Netherlands
- 1903 – First U.S. municipal water installation at Nigara 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; USDA approves ozone for contact with meat and poultry
- ***2012*** – Ozone Solutions launches its new website with over 1,000 pages and 10,000 images!

Nice, France is often credited with the first municipal ozone installation. This is not the case. The first municipal ozone installation was at Oudshroom, The 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

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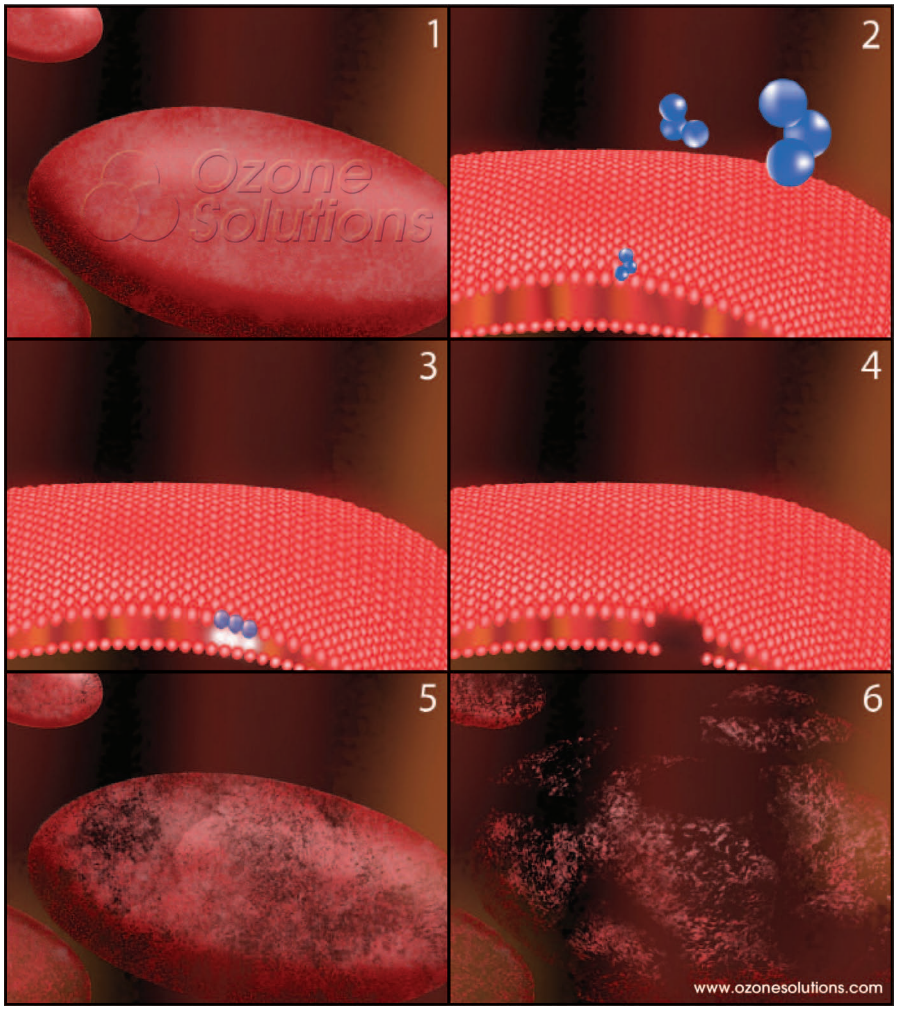
Click to learn more about ***ozone's history***.

How Ozone Kills Bacteria



1. A healthy 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.

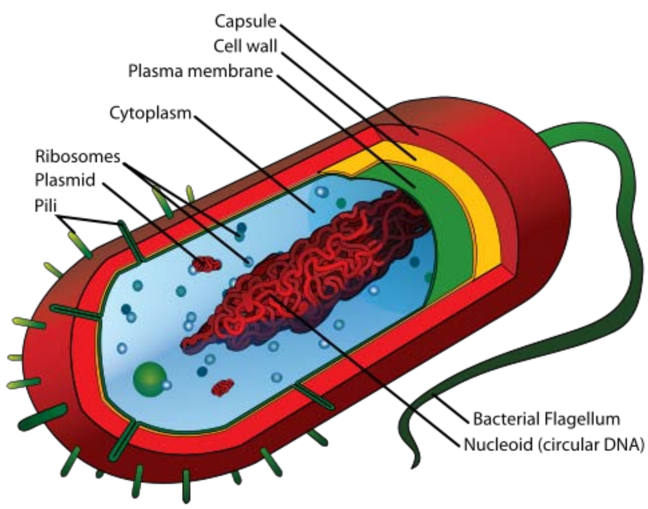
5. The bacterium begins to loose its shape while ozone molecules continue to create holes in the cell wall.

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!

The human body also protects itself via oxidative burst! White blood cells will seek out bacteria in the bloodstream. The bacteria will envelope the white cell. Once inside the cell wall, the white cell will metabolize water into oxidants such as hydroxyl (OH^-) and hydrogen peroxide (H_2O_2). This action destroys the cell from the inside out.

In 2002, the Scripps Research Institute department of chemistry in La Jolla, CA discovered chemical signatures similar to ozone were present during oxidative burst.



Click to learn more about how *ozone can kill bacteria*.

Ozone Effects on Bacteria, Viruses, & Molds

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, and this leads 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”

Bacteria:
Virus:
Mold:

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% reduciton 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% destruciton at 0.035 mg/l for 10-seconds in water
Coxsackie Virus B5	99.99% desctruction at 0.4 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 Virus	Destoryed 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% destruciton 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
Poli ovirus 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 min
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	Ozone causes chromosome aberration and its effect is twice that observed by the action of X-rays

Did you know that, to date, there has not been a single bacterium, virus or cyst discovered that can withstand ozone? Ozone kills them all!

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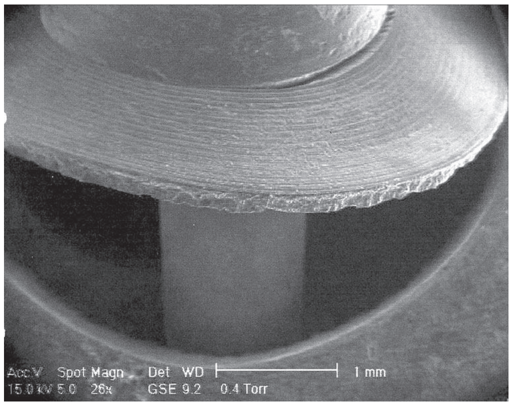
Click here to learn more about the effect of ***ozone destroying bacteria***.

Ozone Compatible Materials

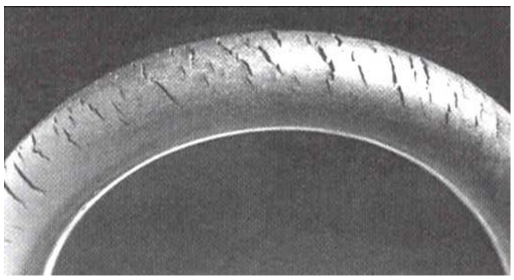
Many of these materials were tested at the Ozone Solution's lab. Some are commonly known and rated as shown by others. All tests were performed at high levels (> 1000 PPM) of ozone concentration.
For any materials not shown, please ***call***. We may have data on file or we can use our labs to test the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

Material	***Rating***
ABS plastic	B
Acetal (Delrin®)	C
Acrylic (Perspex®)	B
Aluminum	C (Wet Ozone) 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) 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 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

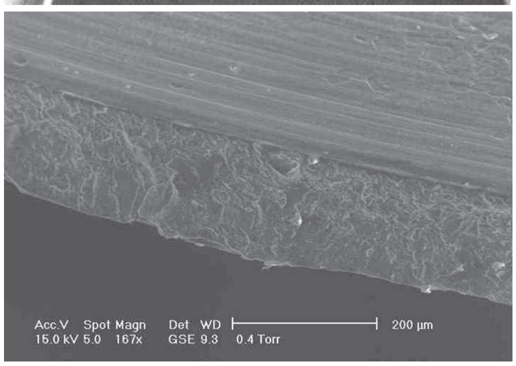
Rating		Description
A	Excellent	Ozone has no effect on these materials. They will last indefinitely.
B	Good	Ozone has minor effect on these materials. Prolonged use with high concentrations of ozone will break down or corrode these materials beyond usefulness.
C	Fair	Ozone will break down these materials 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 recommeneded 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 butadiene 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.

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Click to learn more on the effect ***ozone has on compatible materials.***

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 the advantages and disadvantages.

1 Ambient Air - 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 cell or corona plate.

PROCESS:

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 - Dry Air refers to air which has moisture removed so the dew point is -60 deg 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).

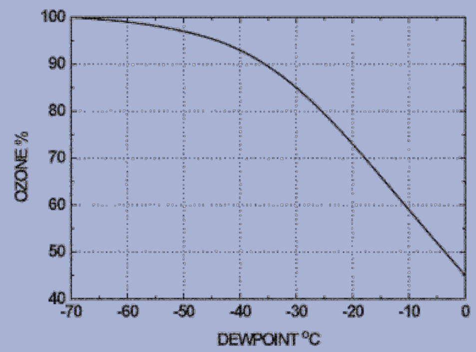


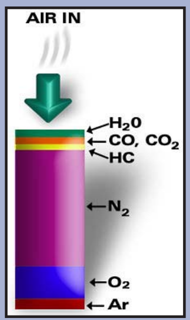
Chart shows how ozone generator output decreases as dewpoint (moisture content) increases. Left axis shows the relative output of the ozone generator. (e.g. At -10 deg C dewpoint, an ozone generator will be producing 60% of its maximum {rated} output.)

PROCESS:

3 Concentrated Oxygen - Concentrated Oxygen refers to oxygen which is of minimum 90% pure with moisture removed -100 deg F dewpoint. It can be produced from an oxygen concentrator or delivered from an oxygen cylinder.

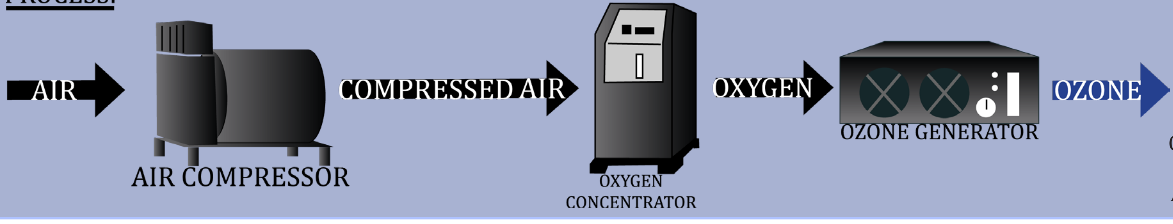
Advantages:
- Allows a consistent ozone output over time.
- Eliminates corona cell maintenance (very important).
- Virtually all moisture is removed.
- Ozone output is typically doubled (2x) vs. using dry air!
- Highter concentrations means very soluble in water.

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).



Oxygen Concentrators generate 90% O^2, 5% Argon & 5% NItrogen

PROCESS:



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Click to learn more about ***generating feedgas for Ozone Generators***.

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 ozone 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 diffusers due to hole size.

Advantages:

- Low cost
- Easy to setup
- Low energy - does not require a water pump

Disadvantages:

- Inefficient - ranges from 10-25% (dependent on water height)
- High water columns/vessels are typically required
- Difficult to use in pressurized water flows
- Diffuser pores can become plugged requring cleaning

The diameter of a gas bubble has a dramatic impact on surface area as shown below!

Be picky when it comes to selecting a bubble diffuser. It can mean the difference between success and failure.

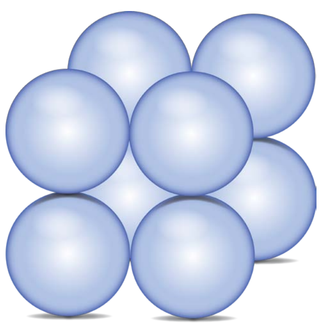
The transfer of ozone gas into water is directly related to its surface area (total bubble surface area).

It is critical to prevent the water from back-flowing through the bubble diffuser and going into the Ozone Generator. The best method of prevention is to use multiple check valves (for redundancy) and a water trap.

Bubble(s) volume = 1 cubic foot.

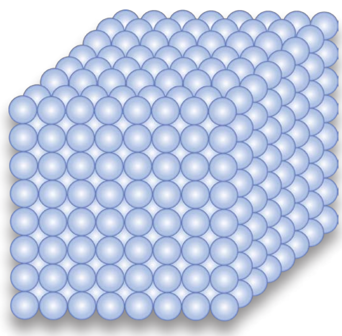
4.8 square feet

14.8-in diameter
Area = 1
1 bubble



185 square feet

10-mm diameter
38.5x Area
54,000 bubbles



1,800 square feet

1-mm diameter
375x Area
54,000,000 bubbles

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!

Conclusion:

Smaller bubbles have much better ozone mass transfer!

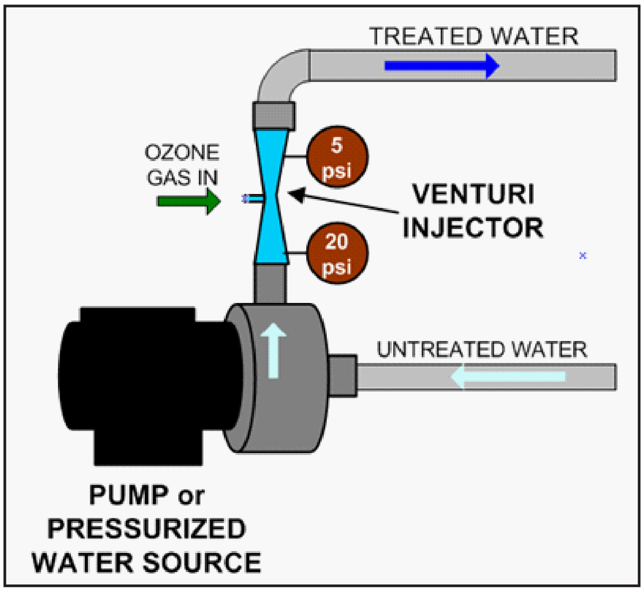
Sources: (*"Supplementary Swimming Pool Treatment" by Poolpakinternational.com - MK2_PTL_OZONE_Rev-20110527.pd.)
www.wastewater.com/techbulletins/117%20What%20is%20a%20Fine%20Bubblex.pdf

Ozone Solutions

Click to learn more about ***ozone transfer via bubble diffusion***.

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. Essentially, ozone gas is slammed into the water.



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

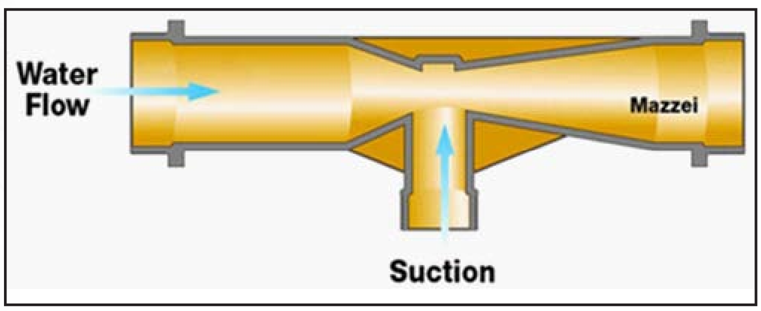
Advantages:

- Mass transfer efficiencies up to 98%*
- Works well in pressurized streams
- Minimal maintenance required
- More controlled & consistant 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).*

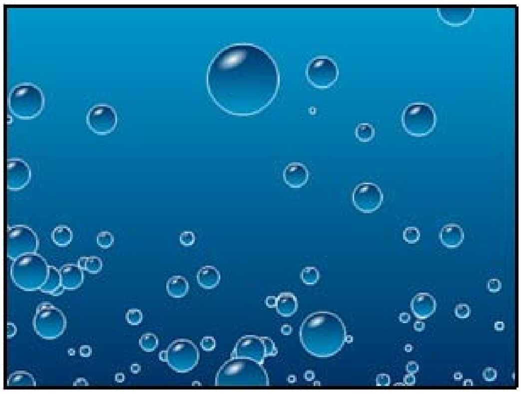
Ozone Solutions®

Click to learn more about ***ozone transfer via Venturi***.

Ozone Solubility in Water

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 that everyone is familiar with is oxygen or O_2. We breath 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!



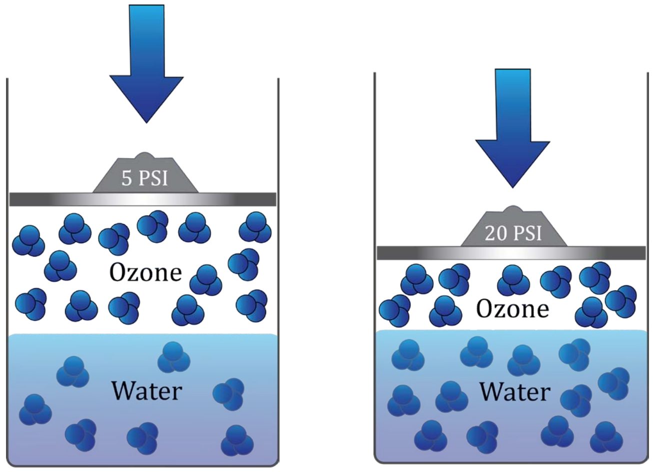
Water at 86° F will have less ozone bubbles than water at 50°F.

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

Conditions which affect the solubility level of a gas into water.

1. One is the temperature of the water. See example pictures above.
2. Another factor is water pressure. Water that is at 35 PSI will have twice the solubility of water at 10 PSI.
3. 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. See the "Pressurized ozone gas" picture below.
4. If the gas that you are placing into the water is at an increased concentration, this will allow additional solubility.
5. The efficiency of the device whose purpose is to entrain the ozone into the water.

Note: Adding any one of the above list to your process will improve the solubility. Incorporating more than one will be even better.

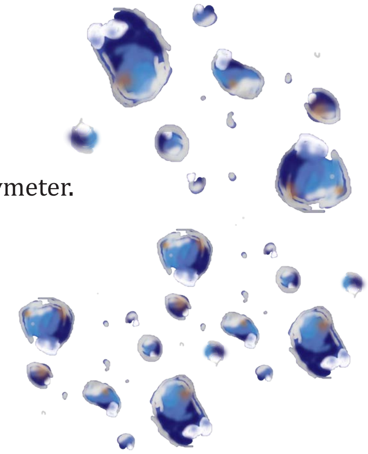


Conclusion: Higher water pressures result in higher dissolved ozone levels.

Ozone Solutions

Click for more information on ***ozone solubility in water***.

Ozone Formulas



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

Adjust Flow Rate Conversion

$$\text{(adjusted flow)} = \text{(measured flow)} \bullet \sqrt{\frac{\text{(oxygen pressure)} + 14.7}{14.7}}$$

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

Below 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 3.78 l/gal x 60 min/hr x ozone dosage (mg/l) = ozone production (mg/hr)

Lets 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 3.78 l/gal x 60 min/hr x 2 PPM = 9,072 mg/hr **(9g/hr)**

Remember that 9 gm/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/m^3) = ozone production (mg/hr)**

Let's work through another example: *The ozone concentration exiting an Ozone Generator is 120 g/m^3 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**

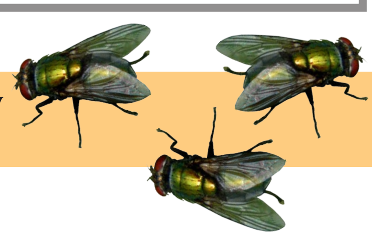
Sample Conversions

Convert 140 g/m^3 to wt% (oxygen feedgas)

Using on the conversion from page 15, 100 g/m^3 = 6.99 wt. %

Therefore 140 g/m^3 / 100 g/m^3 x 6.99 wt. % = ***9.8 wt.%***

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



Ozone Solutions®

Click for ***more ozone formulas***.

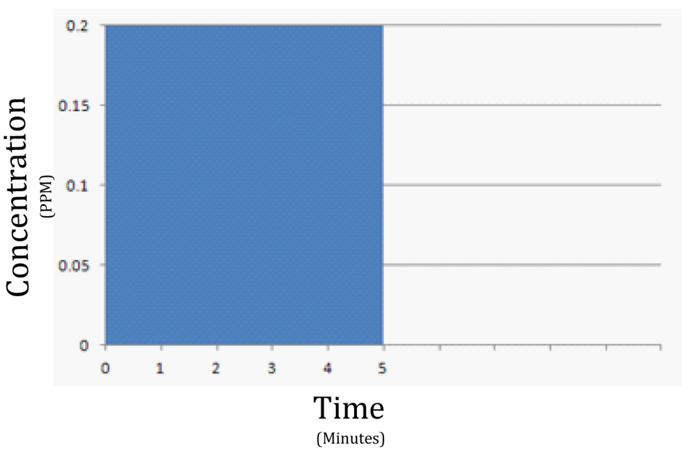
CT Value - What is it?

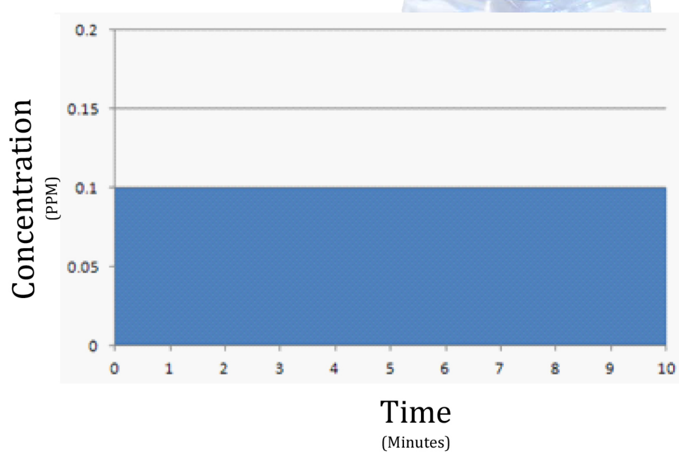
“CT” is the product of “residual disinfectant concentration” (C) in mg/l, and the corresponding “disinfectant contact time” (T) in minutes. In other words, for ozone CT, it is the dissolved ozone concentration multiplied by the contact time. (remember that 1 mg/l = 1 PPM)

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 unitless. 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 doage 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.





Both Charts present a CT value of 1.0, Concentration (PPM) x Time (Minutes)

You may have heard the claim, “ozone is 3,000x more germicidal than Chlorine.” What does this mean? This statement hinges on the fact that for some organisms, you need a CT value 3,000x higher when using chlorine vs. ozone. Put another way, if a dissolved ozone level of 0.2 PPM for 1 minute (CT is 0.2) is needed to inactivate a specific microorganism, you will need 200 PPM of chlorine for 3 minutes (CT = 600) to achieve the same kill effect.

Ozone Solutions®

Click to learn more about CT value.

Ozone Conversions

Physical Properties, Standard conditions P=1013.25 MB, T=273.3 K

- 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
- 1 gal = 3.785 liters = 3, 785 ml
- 1 m^3 = 35.3 ft^3 = 264 US gallons

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
- 100 pphm (parts per hundred million) = 1 ppm (parts per million)

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!

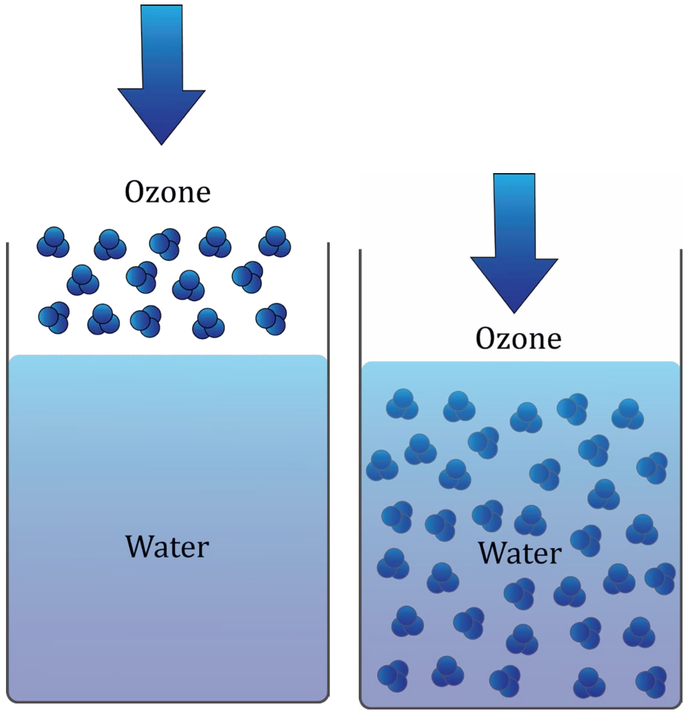
Ozone Solutions®

Click for more information on [*conversions of ozone*]().

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 ineffiencies, 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 ozone: 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 state 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 - see ***how it's done!***.

Ozone Solutions

Click to learn more about ozone dosage vs. dissolved ozone.

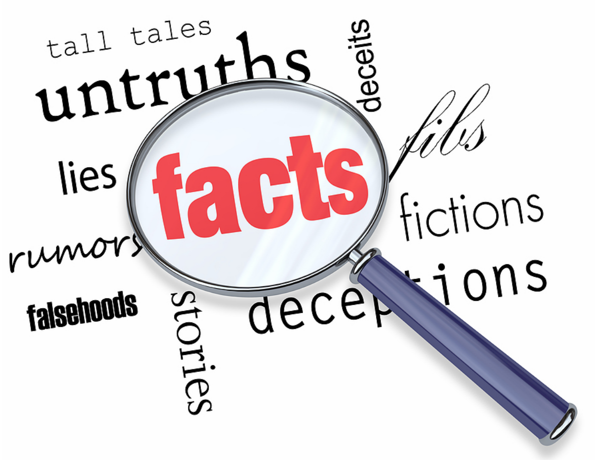
Ozone Fallacies

We've heard them all. Now it's 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. pH level has more effect on corrosion rates of metals than most idustry 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

Ozone Solutions

Click to learn more about ***ozone fallacies***.

FDA & USDA Permit Ozone Use on Food

Can ozone be used on food?

Yes it can!

<u>See official directives below.</u>

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 exists 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. Referernces for all these actions, along with the specific rules are provided below.

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 by the Electric Power Research Institute, Agriculture and Food Technology Alliance.

This rule is effective June 26, 2001.

USDA Reference 21 CFR 173.368
Ozone (CAS Reg. No. 10028—15—6) may be safely used in the treatment, storage, and processing of foods, including meat and poultry (unless such use is precluded by standards of identity in 9 CFR part 319), in accordance with the following prescribed conditions: (a) The additive is an unstable, colorless gas with a pungent, characteristic odor, which occurs freely in nature. It is produced commercially by passing electrical discharges or ionizing radiation through air or oxygen. (b) The additive is used as an antimicrobial agent as defined in § 170.3(o)(2) of this chapter. (c) The additive meets the specifications for ozone inthe Food Chemicals Codex, 4th ed. (1996), p. 277, which is incorporated by reference. The Director of the Office of the Federal Register approves this incorporation by reference in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies are available from the National Academy Press, 2101 Constitution Ave. NW., Washington, DC 20055, or may be examined at the Office of Premarket Approval (HFS—200), Center for Food Safety and Applied Nutrition, Food and Drug Administration, 200 C St. SW., Washington, DC, and the Office of the Federal Register, 800 North Capitol St. NW., suite 700, Washington, DC. (d) The additive is used in contact with food, including meat and poultry (unless such use is precluded by standards of identity in 9 CFR part 319 or 9 CFR part 381, subpart P), in the gaseous or aqueous phase in accordance with current industry standards of good manufacturing practice. (e) When used on raw agricultural commodities, the use is consistent with section 201(q)(1)(B)(i) of the Federal Food, Drug, and Cosmetic Act (the act) and not applied for use under section 201(q)(1)(B)(i)(I), (q)(1)(B)(i)(II), or (q)(1)(B)(i)(III) of the act.

Ozone Solutions

Click to learn more about the ***<u>uses of ozone on food</u>***.

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. tech@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 Eye Irritation – Category 2B 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:	O3
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	-193oC/-315oF	Relative density	NA
Boiling point	-112oC/-169oF	Partition coefficient	NA
Vapor pressure	> 1 atm	Flammability	NA
Vapor density	1.6 (air = 1)	Explosive limits	NA
Solubility in water	570 mg/L @20oC & 100% O3; 0.64 @0oC	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 20oC = 20 min; in dry still air at 24oC = 25 hr; decreases significantly with increase in humidity, presence of contaminants, air movement, and/or increase in temperature.

Preparer: Tim McConnel, Ozone Solutions

Date of Preparation: 5/1/2012

Ozone Solutions®

The Definitive Guide to Understanding Ozone

The good, bad, and ugly of ozone.

Ozone Solutions