Corona Discharge vs. UV Ozone Generation

Ultraviolet (UV) ozone generation
Ultraviolet lamps have been used for decades to generate ozone. This lamp emits UV light at 185 nanometers (nm). Light is measured on a scale called an electromagnetic spectrum and its increments are referred to as nanometers. Figure 1 represents an electromagnetic scale; note the location of higher-frequency ultraviolet light relative to visible light (the range of light perceptible by the human eye).

Air (usually ambient) is passed over an ultraviolet lamp, which splits oxygen (O2) molecules in the gas. The resulting oxygen atoms (O-), seeking stability, attach to other oxygen molecules (O2), forming ozone (O3). The ozone is injected into the water, or air stream, where it inactivates contaminants by actually rupturing the organisms’ cell wall.

Corona Discharge (CD) ozone generation
The technologies involved in corona discharge ozone generation are varied, but all operate fundamentally by passing dried, oxygen-containing gas through an electrical field. The electrical current causes the “split” in the oxygen molecules as described in the section on ultraviolet ozone generation. Past this common feature the variations are many, but the generally accepted technologies can be divided into three types - low frequency (50 to 100 Hz), medium frequency (100 to 1,000 Hz), and high frequency (1,000 + Hz). Since 85% to 95% of the electrical energy supplied to a corona discharge ozone generator produces heat, some method for heat removal is required. Also, proper cooling significantly affects the energy efficiency of the ozone generator, so most corona discharge systems utilize one or more of the following cooling methods: Air or water.

Ozone Being created via Corona Discharge.
At the heart of a corona discharge ozone system is the dielectric. The electrical charge is diffused over this dielectric surface, creating an electrical field, or “corona”.
Critical to CD ozone systems is proper air preparation. The gas feeding the ozone generator must be very dry (minimum -80 degrees F), because the presence of moisture affects ozone production and leads to the formation of nitric acid. Nitric acid is very corrosive to critical internal parts of a CD ozone generator, which can cause premature failure and will significantly increase the frequency of maintenance. The chart below shows that relative ozone output decreases as moisture content increases.
Of the ozone technologies mentioned above, none has a clear advantage. However, to help narrow the field for a particular application, consider the amount of ozone required. You may find that low and medium frequency ozone systems will have prohibitively high initial costs for applications requiring less than ten lbs./day. However, they have a proven history of durability and reliability. High frequency ozone generators seem to have the best combination of cost efficiency and reliability for applications requiring less than ten lbs/day of ozone output.

Advantages of Corona Discharge ozone generation:
- Creates higher quantities of ozone more efficiently
- Corona cell life exceeds the life expectancy of any UV bulb when dry air or oxygen is used
- Small construction allowing generator to be installed in virtually any area
- Highest ozone concentration possible of any type of ozone generation
- Industrial Systems can use preparations of oxygen, doubling the output of ozone per volume vs. dry air
- More cost-effective than UV-ozone generation for large scale high concentration installations.
- Much less electrical energy is required to produce a the same quantity of ozone
- Higher gas phase concentrations means the handling of lower gas volumes

Advantages of Ultraviolet (UV) ozone generation:
- less cleaning required
- easier to clean
- Zero Nitrogen Oxides
- UV (ultraviolet) ozone production is not affected or diminished by humidity
- Our UV units also produce Hydroxyl Radicals as well as ozone. Hydroxyl Radicals are aggressive at killing germs that go through the machine, though they cannot travel throughout a building as their life expectancy is only a few seconds. It is the Ozone our UV Ozone Generators produce that travels throughout the building killing germs during shock treatments.

Disadvantages of UV ozone generation:
- Maximum ozone production rate is two grams/hr per UV bulb - depending on size
- Highest ozone concentration that can be produced by 185-nm UV lamp is 0.2 percent by weight, approximately 10% of the average concentration available by corona discharge. (higher concentrations are needed for proper ozone water treatment and other industrial applications)
- Considerably more electrical energy is required to produce a the same quantity of ozone
- Lower gas phase concentrations of ozone means the handling of much higher gas volumes
- UV lamps solarize over time, requiring periodic replacement (after 9 months of continuous use)

Disadvantages of Corona Discharge ozone generation:
- Ambient air corona discharge systems require periodic cleaning unless pure oxygen or an electronic heated desiccant air drier is used.
- Production of nitrogen oxides when used without pure oxygen feed gas or an electronic heated desiccant air drier
- Humidity affects ALL ambient air fed corona discharge systems - just as static electricity is reduced or eliminated by humidity.
Ozone Odor Control:
See how ozone destroys odors:

Normal oxygen (O2) molecules with two atoms of oxygen.

The electrical current of lightning transforms oxygen (O2) molecules into ozone (O3), activated oxygen.

Activated oxygen (O3) breaks back down into oxygen (O2), as extra atom attaches to pollution molecule.

Extra oxygen atom causes breakdown of pollution into benign substance.

Electric charge transforms Oxygen into OZONE

OZONE (O3) readily sheds an Oxygen atom, becoming Oxygen (O2) and oxidizing pollutants.

Extra Oxygen atom attaches to organic or chemical pollutants; oxidizing, de-odorizing & disinfecting.
Effect of Ozone on Bacteria

1 - Computer generated image of a bacteria cell
2 - Close-up of ozone molecule coming into contact with bacterial wall
3 - Ozone penetrating and creating hole in bacterial wall
4 - Close-up effect of ozone on cell wall
5 - Bacterial cell after a few ozone molecules come into contact
6 - Destruction of cell after ozone (cell lysing)

As a comparison based on 99.99% of bacterial concentration being killed and time taken: Ozone is

- 25 times of that of HOCl (Hypochlorous Acid)
- 2,500 times of that of OCI (Hypochlorite)
- 5,000 times of that of NH2Cl (Chloramine).

Further more, ozone is at least 10 times stronger than chlorine as a disinfectant. Chlorine reacts with meat forming highly toxic and carcinogen compounds called THMs or tri-halomethanes - rendering meats lesser quality products. THMs was also implicated as carcinogens in developing kidney, bladder, and colon cancers. Chlorine also results in the production of chloroform, carbon tetrachloride, chloromethane besides THMs. On the other hand, ozone does not even leave any trace of residual product upon its oxidative reaction.
What is ORP?

ORP is a term used frequently in the water treatment & food processing industry. ORP stands for Oxidation-Reduction Potential. So what is that? The best definition I can give is that “ORP is a measure of the cleanliness of the water & its ability to break down contaminants”. It has a range of −2,000 to + 2,000 and units are in “mV” (millivolts). Since ozone is an oxidizer, we are only concerned with positive ORP levels (above 0 mV).

<table>
<thead>
<tr>
<th>ORP Level (mV)</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-150</td>
<td>No practical use</td>
</tr>
<tr>
<td>150-250</td>
<td>Aquaculture</td>
</tr>
<tr>
<td>250-475</td>
<td>Cooling Towers</td>
</tr>
<tr>
<td>450-600</td>
<td>Hot Tubs</td>
</tr>
<tr>
<td>600</td>
<td>Water Disinfection *</td>
</tr>
<tr>
<td>800</td>
<td>Water Sterilization **</td>
</tr>
</tbody>
</table>

ORP sensors work by measuring the dissolved oxygen. More contaminants in the water result in less dissolved oxygen because the organics are consuming the oxygen and therefore, the lower the ORP level. The higher the ORP level, the more ability the water has to destroy foreign contaminants such as microbes, or carbon based contaminants. The chart on the left identifies ORP levels for various applications.

ORP level can also be viewed as the level of bacterial activity of the water because a direct link occurs between ORP level and Coliform count in water. The chart to the right lists ORP levels and relative Coliform counts.

<table>
<thead>
<tr>
<th>ORP Level</th>
<th>Coliform count in 100 ml of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>300</td>
<td>36</td>
</tr>
<tr>
<td>400</td>
<td>3</td>
</tr>
<tr>
<td>600</td>
<td>0</td>
</tr>
</tbody>
</table>

How does an ORP meter work?

An ORP meter measures very small voltages generated with a probe placed in ozonated water. The electrode is made of platinum or gold, which reversibly looses its electrons to the oxidizer. A voltage is generated which is compared to a silver (reference) electrode in a silver salt solution, similar to a pH probe. The more oxidizer available, the greater the voltage difference between the solutions.

Disadvantages

ORP cannot be used as a direct indicator of dissolved ozone residual, except in very clean water applications.

Advantages

ORP is a convenient measure of ozone’s ability to perform a chemical task. ORP is valid over a wide pH range, and ORP probes are rugged enough to be place into processes for in-line measurement. The probes can withstand process pressures in excess of 30 PSI.

ORP and Ozone

In a clean water system, using ORP to measure the dissolved ozone status works well. In our experience, however, even the strong oxidizing power of ozone in moderate turbidity (cloudiness) systems can result in ORP values far below expected and even negative (reducing) values. In general, monitoring ozone with ORP at the generator source works well but measuring dirty water becomes unreliable.

* Disinfection is destruction of specific pathogenic microorganisms

** Sterilization is the destruction of all microbial life
Ozone Conversions:

**Physical Properties, Standard conditions** $P = 1013.25$ MB, $T = 273.3$ K
- Density of ozone, $2.14$ kg/m$^3$
- Density of oxygen, $1.43$ kg/m$^3$
- Density of air, $1.29$ kg/m$^3$
- Density of water, $1000$ kg/m$^3$

**USEFUL CONVERSION FACTORS** (for water)
- $1000$ liters = $1$ m$^3$ = $264$ US gallons
- $1$ gal = $3.785$ liters = $3785$ ml

**OZONE CONCENTRATION IN WATER**
- $1$ mg/l = $1$ PPM O$3$ = $1$ g O$3$/m$^3$ water (By weight)

**OZONE CONCENTRATION IN AIR BY VOLUME**
- $1$ g O$3$/ m$^3$ = $467$ PPM O$3$
- $1$ PPM O$3$ = $2.14$ mg O$3$/m$^3$

**OZONE CONCENTRATION IN AIR BY WEIGHT**
- $100$ g O$3$/ m$^3$ = $7.8\%$ O$3$
- $1$% O$3$ = $12.8$ g O$3$/m$^3$

**OZONE CONCENTRATION IN OXYGEN BY WEIGHT**
- $100$ g O$3$/m$^3$ = $6.99\%$ O$3$
- $1$% O$3$ = $14.3$ g O$3$/m$^3$

Convert gaseous O$3$ concentration from g/m$^3$ to ppm by volume --- [PPM O$3$ = C / 467]
(Example: $2.14$ g/m$^3$ at standard conditions = $1000$ ppm)

Also:
If we know concentration in g/m$^3$ and flowrate in LPM,
we can calculate output in g/hr

(Example: $28.7$ g/m$^3$ at $2.9$ lpm flowrate)
$28.7$ g/m$^3$ x $2.9$ lpm x $(1$ m$^3$/1,000 l) = $0.083$ g/minute
$0.083$ g/minute x $60$ minutes = $4.9$ g/hr
OZONE EFFECTS ON Specific BACTERIA, VIRUSES AND MOLDS

Bacteria are microscopically small, single-cell creatures having a primitive structure. The bacteria body is sealed by a relatively solid-cell membrane. 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.

Viruses are small, independent particles, built of crystals and macromolecules. Unlike bacteria, they multiply only within the host cell. They transform protein of the host cell into proteins of their own. Ozone destroys viruses by diffusing through the protein coat into the nucleic acid core, resulting in damage of the viral RNA. At higher concentrations, ozone destroys the capsid, or exterior protein shell by oxidation so DNA (deoxyribonucleic acid), or RNA (ribonucleic acid) structures of the microorganism are affected.

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspergillus Niger (Black Mount)</td>
<td>Destroyed by 1.5 to 2 mg/l</td>
</tr>
<tr>
<td>Bacillus Bacteria</td>
<td>Destroyed by 0.2 m/l within 30 seconds</td>
</tr>
<tr>
<td>Bacillus Anthracis (causes anthrax in sheep, cattle and pigs. Also a human pathogen)</td>
<td>Ozone susceptible</td>
</tr>
<tr>
<td>Bacillus cereus</td>
<td>99% destruction after 5-min at 0.12 mg/l in water</td>
</tr>
<tr>
<td>B. cereus (spores)</td>
<td>99% destruction after 5-min at 2.3 mg/l in water</td>
</tr>
<tr>
<td>Bacillus subtilis</td>
<td>90% reduction at 0.10-PPM for 33 minutes</td>
</tr>
<tr>
<td>Bacteriophage F2</td>
<td>99.99% destruction at 0.41 mg/l for 10-seconds in water</td>
</tr>
<tr>
<td>Botrytis cinerea</td>
<td>3.8 mg/l for 2 minutes</td>
</tr>
<tr>
<td>Candida Bacteria</td>
<td>Ozone susceptible</td>
</tr>
<tr>
<td>Clavibacter michiganense</td>
<td>99.99% destruction at 1.1 mg/l for 5 minutes</td>
</tr>
<tr>
<td>Cladosporium</td>
<td>90% reduction at 0.10-PPM for 12.1 minutes</td>
</tr>
<tr>
<td>Clostridium Bacteria</td>
<td>Ozone susceptible</td>
</tr>
<tr>
<td>Clostridium Botulinum Spores. Its toxin paralyses the central nerve system, being a poison multiplying in food and meals.</td>
<td>0.4 to 0.5 mg/l threshold value</td>
</tr>
<tr>
<td>Coxsackie Virus A9</td>
<td>95% destruction at 0.035 mg/l for 10-seconds in water</td>
</tr>
<tr>
<td>Coxsackie Virus B5</td>
<td>99.99% destruction at 0.4 mg/l for 2.5-minutes in sludge effluent</td>
</tr>
<tr>
<td>Diphtheria Pathogen</td>
<td>Destroyed by 1.5 to 2 mg/l</td>
</tr>
<tr>
<td>Eberth Bacillus (Typhus abdomanalis). Spreads typically by aqueous infection and causes typhoid.</td>
<td>Destroyed by 1.5 to 2 mg/l</td>
</tr>
<tr>
<td>Echo Virus 29: The virus most sensitive to ozone.</td>
<td>After a contact time of 1 minute at 1 mg/l of ozone, 99.999% killed.</td>
</tr>
<tr>
<td>Enteric virus</td>
<td>95% destruction at 4.1 mg/l for 29 minutes in raw wastewater</td>
</tr>
<tr>
<td>Escherichia Coli Bacteria (from feces)</td>
<td>Destroyed by 0.2 mg/l within 30 seconds in air</td>
</tr>
<tr>
<td>E-coil (in clean water)</td>
<td>99.99% destruction at 0.25 mg/l for 1.6 minutes</td>
</tr>
<tr>
<td>E-coil (in wastewater)</td>
<td>99.9% destruction at 2.2 mg/l for 19 minutes</td>
</tr>
<tr>
<td>Encephalomyocarditis Virus</td>
<td>Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l.</td>
</tr>
<tr>
<td>Endamoebic Cysts Bacteria</td>
<td>Ozone susceptible</td>
</tr>
<tr>
<td>Enterovirus Virus</td>
<td>Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l.</td>
</tr>
<tr>
<td>Pathogen</td>
<td>Dosage</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>Fusarium oxysporum f.sp. lycopersici</td>
<td>1.1 mg/l for 10 minutes</td>
</tr>
<tr>
<td>Fusarium oxysporum f.sp. melongeae</td>
<td>99.99% destruction at 1.1 mg/l for 20 minutes</td>
</tr>
<tr>
<td>GDVII Virus</td>
<td>Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l.</td>
</tr>
<tr>
<td>Hepatitis A virus</td>
<td>99.5% reduction at 0.25 mg/l for 2-seconds in a phosphate buffer</td>
</tr>
<tr>
<td>Herpes Virus</td>
<td>Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l.</td>
</tr>
<tr>
<td>Influenza Virus</td>
<td>0.4 to 0.5 mg/l threshold value</td>
</tr>
<tr>
<td>Klebs-Löffler Bacillus</td>
<td>Destroyed by 1.5 to 2 mg/l</td>
</tr>
<tr>
<td>Legionella pneumophila</td>
<td>99.99% destruction at 0.32 mg/l for 20 minutes in distilled water</td>
</tr>
<tr>
<td>Luminescent Basidiomycetes (species having no melanin pigment)</td>
<td>Destroyed in 10 minutes at 100-PPM</td>
</tr>
<tr>
<td>Mucor piriformis</td>
<td>3.8 mg/l for 2 minutes</td>
</tr>
<tr>
<td>Mycobacterium avium</td>
<td>99.9% with a CT value of 0.17 in water</td>
</tr>
<tr>
<td>Mycobacterium fortuitum</td>
<td>90% destruction at 0.25 mg/l for 1.6 minutes in water</td>
</tr>
<tr>
<td>Pseudomonas Bacteria</td>
<td>Ozone susceptible</td>
</tr>
<tr>
<td>Phytophthora parasitica</td>
<td>3.8 mg/l for 2 minutes</td>
</tr>
<tr>
<td>Poliovirus type 1</td>
<td>99.5% destruction at 0.25 mg/l for 1.6 minutes in water</td>
</tr>
<tr>
<td>Proteus Bacteria</td>
<td>Very susceptible</td>
</tr>
<tr>
<td>Pseudomonas Bacteria</td>
<td>Very susceptible</td>
</tr>
<tr>
<td>Rhabdovirus virus</td>
<td>Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l</td>
</tr>
<tr>
<td>Salmonella Bacteria</td>
<td>Very susceptible</td>
</tr>
<tr>
<td>Salmonella typhimurium</td>
<td>99.99% destruction at 0.25 mg/l for 1.67 minutes in water</td>
</tr>
<tr>
<td>Schistosoma Bacteria</td>
<td>Very susceptible</td>
</tr>
<tr>
<td>Staphylococci</td>
<td>Destroyed by 1.5 to 2.0 mg/l</td>
</tr>
<tr>
<td>Stomatitis Virus</td>
<td>Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l</td>
</tr>
<tr>
<td>Streptococcus Bacteria</td>
<td>Destroyed by 0.2 mg/l within 30 seconds</td>
</tr>
<tr>
<td>Verticillium dahliae</td>
<td>99.99% destruction at 1.1 mg/l for 20 minutes</td>
</tr>
<tr>
<td>Vesicular Virus</td>
<td>Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l</td>
</tr>
<tr>
<td>Virbio Cholera Bacteria</td>
<td>Very susceptible</td>
</tr>
<tr>
<td>Vicia Faba progeny</td>
<td>Ozone causes chromosome aberration and its effect is twice that observed by the action of X-rays</td>
</tr>
</tbody>
</table>
Ozone and Color Removal

Many wastewater and textile processors are gradually substituting chlorine with ozone. Ozone is a powerful oxidizing mean and safer in use in comparison with other oxidizing means.

Wastewater & Dye color removal

Water is shown colored when visible radiation is absorbed from dissolved materials, or when light is reflected on suspended solids. These two sources of color are the base for the distinction between the pseudo and true color. The pseudo color is due to absorption as well as light reflection. The true color depends exclusively from the kind and quantity of the dissolved substances. Particles with a size of 400-800 nm, that means within the wavelength of visible light, are responsible for light reflection. It is possible with filtering (membrane 0.45 µm) the phenomenon of reflection to be eliminated. It must also be noted that the difference between the pseudo and true color is related to water’s turbidity.

The units Pt–Co (USA), or mg Pt-Co / l (Europe) are defined as color measurement units. These units are considered equivalent. The acceptable limits of color values for the disposal of treated wastewater ranges from 50-100 units Pt-Co, depending on the nature of the receiver (river, sea, lake etc).

True color is created by the presence of compounds that absorb visible light in wavelengths of 400-800 nm, or from compounds that fluoresce in the 200-400 nm spectrum. These are compounds of poly-aromatic structure, substituted aromatic structure, polyenia, concentrated heterocircular molecules or perplex ions. It should be noted that ? bonds absorb into the UV (?200nm ) spectrum and the existence of conjugate bonds (polyenia) is necessary for the absorption in visible light spectrum. Most compounds responsible for color creation contain one or more aromatic rings and start absorbing color at 250 nm.

The synthetic color carriers come mainly from industrial plants as dye-houses, clothing industries with washing-machines, food and beverage industries, slaughterhouses etc.

Wastewater is processed with ozone after its exit from the chemical or/and biological treatment plant and the usual dosage varies from 50-150 mg/l, according to the wastewater origin, its temperature, and the degree of its previous process.

Ozone-wastewater contact system:

The contact system consists of a three-chamber tank, height of 4.5-5 meters with inside splits that guide the wastewater to a vertical labyrinthine flow. Ozone is supplied to the tanks through diffusers made of a special porous material of high resistance. These diffusers have the ability to create multi-numbered and very thin ozone bubbles, with a diameter of 220?m. With their appropriate geometric installation in the bottom of the contact tank, better distribution but also increase in the liquid-gas contact surface to its maximum, is achieved.

The diffuser is used due to the high rate of transport (70%) and its trivial energy consumption. In a tank of three-chambers, diffusers are installed in depth of 5 meters and succeed a transport rate more than 75%. The wastewater must have a hydraulic retention time greater than 45 minutes.

Color Removal Quality:

The quality of the ozone treatment effluent in terms of color removal, depends on:

- the color values of the feed
- the ozone dosage
- the wastewater type (Typically color values do not decrease below 200 Pt-Co units even if an especially high ozone dosage is applied)
- the wastewater temperature (better results with effluent from the existing treatment whose temperature is much lower than the temperature of wastewater from the equalization tank)
- the values of the other wastewater characteristics that ozone also affects (better results if BOD, COD and SS have already been decreased in a previous treatment level)
The best results concerning color removal are achieved if the wastewater has been previously treated in order to lower the values of the other characteristics so that the ozone oxidizing effect is “consumed” only or at least at a maximum proportion in color removal. Additionally the temperature must be below 30-deg C in order to achieve the best physical conditions for its solubility.

The above remark certainly concerns the practical usage of ozone technology in wastewater treatment, as it indicates that the increase of the ozone dosage could give good results even in unprocessed wastewater as long as it has been efficiently cooled.

Wastewater color removal requires an ozone dosage which in most cases fluctuates from 50 to 100 mg/l, for color reduction of 85-92%. This dosage succeeds simultaneously a COD reduction about 40%, while small increases of BOD in the area of 3-7% have been noticed.

The ozone treatment installation represent a significant construction and purchase cost. On the other hand a conventional treatment scheme using chemical coagulants for color removal, has high operational costs (cost of the coagulants themselves and cost for the produced sludge management requirements). In general and for the same effluent quality, the investment of an ozone installation can be paid off in 3-5 years, depending on the size and other specific details of each case.

Written by: Konstantinos J. Delimpasis - Chemical Engineer
Automatic ozone injection, filtration and recirculation system for iron, manganese

Formula for calculating size of generator:

Step 1: decide how much ozone you need by analyzing water. For each mg/l of:
- Iron: Use .4 to .7 mg/l ozone
- Manganese: Use .5 to 1.0 mg/l ozone
- Hydrogen Sulfide: 2.2 to 3.3 ozone

Step 2: Determine flow rate in gallons per minute.

Step 3: Use formula: GPM X .0121 X desired dosage in ppm = lbs per day required.

Example: 3.0 ppm of iron, 1.0 ppm manganese:
- 1.7 ppm of ozone required. Flow rate is 10 gpm
- 10 X .0121 X 1.7 = .2 lbs per day

Ozone systems are sized in lbs per day, or grams per hour for the smaller units.

So convert lbs per day to grams per hour by:
- 1 lb = 448 grams so 448 x .2 = 89 grams per day
- or 3.8 grams per hour.

NOTE: other factors such as pH, and turbidity can affect ozone demand, so it can be important to size for more capacity than is calculated and adjust actual output of ozone, or vary flow rate to achieve desired results.
The four steps to successful treatment with ozone are;
- Gather good information.
- Determine ozone demand.
- Determine equipment and chemical needs.
- Design new ozone based treatment system.

1. Gather good information.

Use a questionnaire to facilitate the information gathering process. A diligently completed questionnaire with good water quality information will serve as the basis of your treatment system design and guide to specifying the correct equipment.

1.1. Fill out the questionnaire.

Make copies of the Project Form in your Professional Residential Dealer Catalog from O₃ Water Systems. Use the questionnaire as an opportunity to thoroughly investigate and gather essential information that can make the difference between successful ozone treatment and failure.

If you are not familiar with the application of ozone or have had hit and miss success, you are encouraged to fax a copy of the completed questionnaire to O₃ Water Systems. O₃ Water Systems will gladly assist with system design and equipment specifications until you are comfortable with the entire process.

1.2. Test the Water.

It is recommended that you have a water analysis performed by a certified laboratory. Be sure to have an analysis done to determine levels of each contaminant you will be treating in the water. If possible get the results from several analyses performed over a period of time to determine if there are seasonal variations in the water supply and what the variations are. If you suspect high levels of organics there are two other tests that will help with system design. They are the Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) of the water you are treating. The COD and BOD results will bear on calculating total ozone demand and treatment system design.

Some water quality information is best gathered "on-site" because the test must be performed immediately upon taking a water sample for the results to be of any value to the treatment design. The information best gathered "on-site" includes the level of hydrogen sulfide (H₂S) and water temperature. Less sensitive to time but more relevant if monitored immediately is the Oxidation/Reduction Potential (ORP) of the water to be treated.

For residential potable water treatment systems it is recommended that at minimum you have the ability to test for the items listed in Table 1:

<table>
<thead>
<tr>
<th>Iron</th>
<th>Manganese</th>
<th>Hydrogen Sulfide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tannins</td>
<td>Temperature</td>
<td>pH</td>
</tr>
<tr>
<td>Ozone</td>
<td>Hardness</td>
<td>Alkalinity</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>Nitrates</td>
<td>Nitrites</td>
</tr>
</tbody>
</table>
2. Determining the ozone demand

Most ozone generators designed for residential water treatment are sized by the grams of ozone produced per hour of operation. To choose the right sized ozone generator for each job you must determine the potential work ozone can do. This work can also be thought of as the ozone demand, of the water.

Determining the ozone demand of the water requires an accurate water analysis and a little math using the demand each contaminant places on ozone, or the amount of ozone required to oxidize the contaminant. The amount of ozone needed for oxidation is known as the demand on ozone or the required dosage. There are as many different demand or dosage figures as there are people calculating ozone treatment. The dosage figures in Table 3 are the figures we use at O3 Water Systems when calculating ozone demand. We have found the dosages in Table 2 to be very successful and reliable in our ozone treatment system designs.

### Table 2

<table>
<thead>
<tr>
<th>Contaminant &amp; Chemical Symbol</th>
<th>Mg Ozone, per Mg of contaminant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>0.43mg</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>0.87mg</td>
</tr>
<tr>
<td>Hydrogen Sulfide (H₂S)</td>
<td>3.0mg</td>
</tr>
<tr>
<td>Tannins</td>
<td>0.1mg</td>
</tr>
<tr>
<td>For Disinfection</td>
<td>0.5mg</td>
</tr>
</tbody>
</table>

**Demand Formula:**

\[
\text{Gr./hr} = \text{L/hr} \times \text{O}_3\text{D}
\]

\[
\text{Gr./hr} = \text{Grams of ozone per hour}
\]

\[
\text{L/hr} = \text{Liters per hour flow rate to be treated.}
\]

\[
\text{O}_3\text{D} = \text{Ozone demand in mg/l to treat the contaminants in the water.}
\]

There are three basic steps to calculate the Gr./hr of Ozone needed to treat the water.

**Step 1:** Calculate the flow rate to be treated in L/hr.

If your data states the flow rate in gallons per minute you must multiply that rate by 60 to determine the equivalent flow rate in gallons per hour. Then multiply the gallons per hour figure by 3.785 to determine the equivalent flow in L/hr.

**Step 2:** Determine the contaminant demand on ozone by multiplying the mg/l of each contaminant found in your water and adding 0.5 mg/l for disinfection to the sum total.

\[
\text{Fe demand} = X \times 0.43 = \text{mg/l}
\]

\[
\text{Mn demand} = X \times 0.87 = \text{mg/l}
\]

\[
\text{H}_2\text{S demand} = X \times 3.0 = \text{mg/l}
\]

\[
\text{Tannins demand} = X \times 0.1 = \text{mg/l}
\]

For Disinfection add 0.5 mg/l (add demands to get total demand)

\[
\text{Sum Total} = \text{mg/l} = \text{mg/l}(\text{O}_3\text{)} \text{ demand} = \text{O}_3\text{D}
\]

**Step 3:** Multiply \(\text{O}_3\text{D}\) by L/hr to calculate mg/hr

**Step 4:** Divide by 1000 to convert to grams per hour needed to treat the water.
Computation Example:

Water sample shows 1.7 mg/l Fe and the flow to be treated is 5 gpm;

**Step 1:** Convert gpm flow rate to liters per hour (l/h);

\[ 5 \text{ gpm} \times 60 \times 3.785 = 1135.5 \text{ L/hr.} \]

**Step 2:** Determine the contaminant demand on ozone;

\[ 1.7 \text{ mg/l Fe} \times 0.43 = 0.731 \text{ mg/l} + 0.5 \text{ mg/l (for disinfection)} = 1.231 \]

**Step 3:** Multiply O$_3$D by rate of flow;

\[ 1135.5 \text{ l/h} \times 1.231 \text{ mg/l} = 1397.8 \text{ mg/hr;} \]

**Step 4:** Divide by 1000 to convert from milligrams to grams;

\[ 1397.8 \div 1000 = 1.4 \text{ gr./hr Total Ozone Demand.} \]

Keep in mind that ozone will react first with H2S, then with Fe followed by Mn and lastly with Tannins. There are other things, such as temperature of the water, organically bound compounds, or seasonal variations that bear on the exact ozone treatment system design. It would be sensible to figure a slightly higher (perhaps 20%) ozone demand and increase contact time to factor in unknowns.

To treat surface waters some will say that having a residual of ozone after appropriate contact time is all that is needed. We recommend that when treating surface waters with bacteria, virus, or cysts and multiple other oxidizable contaminants that ozonation be a two step process. In step one, ozonation and filtration will purify the water (remove iron, manganese, hydrogen sulfide, etc.). In step two, ozone will again be injected and a ozone residual will be maintained to insure disinfection. A possible alternative to the second point of ozone injection could include the use of Giardia approved filter systems or ultra-violet radiation post filtration.

### 3. Determine Equipment and Chemical needs

Each component of the ozone treatment system must be properly sized to work together and produce treated water at the required rate of flow.

#### 3.1. Ozone Injection

There are two most common methods of injecting ozone into the water, using a pump to force ozone through a diffuser and venturi injection. We prefer venturi injection because it is very efficient and requires no moving parts. Water pressure at the inlet of the venturi injector must be higher than the outlet pressure during the entire pump cycle. This difference is known as the pressure differential. The pressure differential required for each treatment system is determined by two variables.

**Variable 1.**

Required rate of injection, stated as liters per minute (l/m) or equivalent Standard Cubic Feet per Hour (SCFH). The required rate for your ozone generator can be obtained from your ozone equipment or manufacturer. Request a chart showing various rates of ozone production at various injection rates. Proper use of this information will enable a certain amount of “customization” for each application.

**Variable 2.**

The selected venturi injector. Again, use the injector charts to select an injector that meets or exceeds the required injection rate set by your ozone equipment manufacturer.
3.2. Ozone Contact and off-gas.

After injection the ozone must have time to do its work. This time is known as contact time. Contact time is the time ozone has to oxidize and disinfect or the time the water is allowed to hold the disinfectant. For ozone, contact time is measured from the point of injection to the filter. Depending upon the circumstances of each installation, there may still be ozone in the water after filtration but for purposes of calculating contact time, the filter marks the end. Suppose you inject ozone into a 25 gallon contact vessel followed by a filter and the flow rate is 5 gpm, the contact time in this situation would be 25 gallons divided by 5 gallons per minute resulting in 5 minutes contact time.

The contact time needed varies with the matter to be oxidized. Time required for oxidation ranges from almost instantly to 10 minutes or more. A general rule of thumb is no less than 4 minutes contact time with a measurable residual of 0.1-mg/l ozone and more contact time is better. Don’t take a good thing too far, because ozone is so fast reacting and has such a short life once generated it is possible to have too much contact time in which case you wouldn’t have a measurable residual.

There are several reasons more contact time is better, here are two:
1. Contaminants floc or precipitate at varying rates and with varying degrees of density, giving more time will often make a treatment system a success by providing time for material to fully precipitate which in turn enhances filterability.
2. Ozone must contact the contaminant to oxidize or disinfect; more contact time increases the odds that all water will be subjected to oxidation.

If using ozone to disinfect, there are guidelines set by the Environmental Protection Agency (EPA). The EPA has proposed the use of a "CT value" to assure the attainment of primary disinfection at a minimum cost. The CT value is the numerical product of the concentration of residual disinfectant ("C"), in mg/l, multiplied by the time (T), in minutes, during which the residual is present.

\[ C \text{ (mg/l) x T (min.) =} \]
\[ \text{CT value (mg/l-min)} \]

Thus, units for CT-values are expressed as mg/l-min.

CT tables show the required CT value at a given temperature and pH. To be more precise and meet regulatory requirements please refer to the approved CT tables used by the regulating authority in your area. Most agencies use the EPA recommended CT values.

All gasses inducted through the venturi must be properly disposed of or "off-gassed". At a bare minimum, this is accomplished by simply venting the contact tank to the outside. It may be required to route the gasses through an ozone destruct unit to insure no ozone gasses are being emitted from the treatment system.

3.3. Filtration of oxidized particulate.

At O₃ Water Systems we most often specify multi-media filtration with our ozonation systems. In most cases, a properly sized multi-media depth filter is very well suited to filtering objectionable oxidized contaminants and will give years of operation with little required maintenance. In some cases a series of filters will be needed to accomplish adequate filtration. Circumstances (usually regulatory enforcement of the SWTR) may require additional filtration to physically remove Giardia and/or Cryptosporidium.

It is recommended that activated carbon filtration be used as a final filtration step to remove any dissolved ozone potentially remaining in the water.
4. System Design

There is no one right ozonation system design. With ozone there is a great deal of design flexibility, please refer to manufacturers guidelines for proper design and installation of their ozonation equipment.

There are a few rules that must be followed no matter which ozone manufacturers equipment you are using.

1. Safety precautions must be taken to prevent prolonged exposure to ozone gas by humans or other animals.
2. All materials in contact with ozone must be ozone resistant.
3. Atmospheric conditions where the equipment is installed must be favorable to highly sophisticated electrical equipment. Please consider temperature, humidity, exposure, etc.

Many ozonation systems will be replacing a treatment system using another oxidation/reduction process. It can be (with customer consent) to everyone’s benefit to incorporate as much of the existing system as possible into the new ozone treatment system (be sure any warranty issues are resolved and to note the items for re-use on your completed questionnaire).

The most commonly adaptable components are system pumps, contact tanks, filters and holding tanks. Be sure that all the components are ozone resistant. Beware of using any non-stainless steel metal tanks and pumps where ozone will be in contact. Ozone will oxidize them too!

Because ozone is a stronger oxidant and more reactive than other oxidizers it is likely that any existing ozone compatible contact/storage tanks will be adequately sized. Filter media in existing filters may need to be changed and it may be necessary to update the filter control valve.

4.1. Two Basic Design Models to Choose From – Pressure Systems and Atmospheric System

What is meant by a “pressure system”?
A treatment system that is consistently under greater than atmospheric pressure during the entire treatment process is considered a pressure system. A pressure system is found most often where the water is not too bad and the flow rates are low (usually less than 10 gpm).

What is meant by an "atmospheric system"?
A treatment system that is not constantly under pressure greater than atmospheric. An atmospheric system will most always have 1 or more pumps to re-pressurize after water comes to atmospheric pressure.

What are some of the differences between pressure and atmospheric systems?
Pressure aside, some of the differences between pressure and atmospheric systems are highlighted in Table 3.
Table 3.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Pressure Systems</th>
<th>Atmospheric Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The treatment system remains under pressure during the entire treatment process.</td>
<td>The treatment system comes to atmospheric pressure at some point during the treatment process.</td>
</tr>
<tr>
<td>Cost</td>
<td>May be less expensive (especially where the water to be treated is relatively clean and the volume of water to be treated is low).</td>
<td>May be less expensive where water is very dirty (especially where the volume of water to be treated is over 10 gpm).</td>
</tr>
<tr>
<td>Suitability</td>
<td>Most suitable in residential treatment systems treating less than 10 gpm and where there is at least a 80 gallon pressure tank.</td>
<td>Suitable for any size treatment system.</td>
</tr>
<tr>
<td>Advantages</td>
<td>Simple design. Requires only one pump. Lower system space requirements.</td>
<td>Flexible treatment design. Can incorporate multiple injection points. Easier to control ozone residual levels. Can use smaller ozone generator with recirculation through the contact tank.</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Single injection point. May require a larger ozonation system for single point injection. The single pump used to supply the treatment system may need to be larger to insure the pressure differential across the venturi injector is maintained during the entire pump cycle. A larger pump requires more power.</td>
<td></td>
</tr>
</tbody>
</table>

Two common questions;

**Will ozone take out hardness?**
Ozone will not oxidize hardness minerals such as calcium. Incorporating a softener into your ozone water treatment system to remove hardness requires only two special considerations, whether all components are ozone compatible and where to place it. In a treatment system where ozone is employed, a softener is installed after oxidation and filtration processes. Using ozone before your softener will likely decrease the work load of the softener as contaminates such as iron are removed prior to the softener and taken out of the softener sizing equation. This leaves only the hardness minerals for the softener to contend with and may reduce the size of softener needed and its operating cost while extending its service life.

**Will ozone fix my low pH?**
Ozone will not directly effect Low pH. Though ozone is relatively unaffected by normally encountered pH levels, if possible, adjust pH prior to ozonation as some contaminants are more readily removed with ozone where the pH is between 6.0 and 9.0. pH can be adjusted in a treatment system based on ozone just as it would without ozone.