



W A T E R

Cal Water

Industrial Water Purification

(800) CAL-WATER

TOC Destruction/ Total Organic Carbon (TOC) Fact Sheet

Total Organic Carbon

Total Organic Carbon (TOC) is defined as any compound containing the carbon atom, except CO₂, and related substances such as carbonate, bicarbonate and the like. The carbonates are considered to be "Fully Oxidized" and are therefore not constituents of TOC. Considering this exception to the definition of TOC, a more appropriate definition of TOC might be "Total Oxidizable Carbon."

Total organic carbon (TOC) can be found in most city water as naturally occurring microorganisms, other organic matter and man-made organic-based chemicals. Naturally occurring TOC has frequently been found to be a seasonal phenomenon, often requiring more aggressive treatments depending on the time of year. In cases of extremely high TOC loads, (>1,000 ppm), municipal chemical treatment by coagulation and settling using alum or iron salts effectively reduces them to a manageable level for the public.

Low to moderate organic loads can be removed from water in a number of ways:

Activated Carbon (GAC)

Activated carbon will adsorb any organic, ionized or otherwise. By reducing the TOC load, an activated carbon filters can play a beneficial role ahead of a high purity water system such as a reverse osmosis unit or a deionizer.

But activated carbon frequently contains leachables, is non-regenerable and can become a breeding ground for microorganisms. Activated carbon is usually a poor choice for TOC removal following a high purity water system.

Strong Base Anion Resin

Strong base anion ion exchange resins have been used to adsorb slightly ionized organics. But even though the resin is regenerable, the system must be set up properly or the adsorbed organics can foul the resin. Further, the pH of the effluent from strong base resin will vary depending on the regenerant chemical.

Neither of the above treatment methods are reliable or cost effective for the removal of low level TOC down stream of high purity water systems.

There are two practical approaches for the reduction-removal of Low-level TOC (<10 ppm = 10,000 ppb) in high purity water:

1. **Exclusion:** Reverse Osmosis membranes do an excellent job of rejecting large, non-volatile organics and microorganisms.

2. **Oxidization:** Chemical oxidation and/or photooxidation destroys organic compounds to effectively reduce the TOC load in high purity water, and can be designed to kill and disassemble any microorganisms that may somehow invade the system.

The above TOC removal techniques are not mutually exclusive. Frequently in industry and laboratory applications, both are employed to reduce the native TOC to an acceptable level.

Exclusion

Reverse Osmosis membranes operate by rejecting larger charged ions from the smaller non-charged water molecules. Contaminants such as Na⁺, K⁺, SO₄⁼, and Cl⁻ are rejected quite well with today's membranes. Since non-volatile organics have a tendency to be large, they are rejected as well or better than inorganic contaminants.

But volatile organics, like all gasses, pass through RO membranes preferentially. Since RO will reject the larger organics very effectively, and the larger organics are difficult to oxidize anyway, an effective TOC removal system will include an RO unit. Once the larger organics have been removed, the volatile organics that do come through the membrane can be effectively and almost quantitatively oxidized, usually by a simple 185>254 UV sterilizer setup.

Oxidation

Injection of an oxidizer such as reagent grade hydrogen peroxide will destroy organic compounds. Similarly, an ultraviolet radiation (UV) reaction chamber, properly setup will produce the low TOC levels.

Hydrogen Peroxide Injection

Reagent grade hydrogen peroxide will do an excellent job of oxidizing stubborn organics. But in practice it is difficult to control, and therefore almost never used alone in high purity water systems. Hydrogen peroxide injection can be used very effectively in conjunction with an oversized 254 nm UV sterilizer and can done so for two reasons:

- 254 nm UV radiation destroys any residual hydrogen peroxide.
- The combination of peroxide and 254 nm UV is an order of magnitude more effective than either oxidizer alone.

While this combination system is quite effective, great care must be used in the design and startup of such a system. Safeguards must be employed such as an ORP (Oxidation-Reduction Potential) monitor on the outlet and a TOC analyzer on the inlet.

Ozone Injection

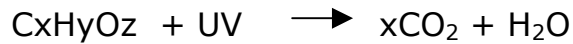
The injection of ozone ahead of a 254 nm UV unit can be quite effective in TOC removal, but the system must be set up to exclude gas bubbles with an interceptor tank with a gas purge mechanism. Undissolved gas bubbles in the water can render a following 254 nm UV sterilizer ineffective. Ozone injection, properly applied, can be very effective when used in conjunction with a 254 nm UV sterilizer:

- 254 nm UV radiation destroys ozone.
- The combination of ozone (or any other oxidizer for that matter) combined with 254 nm UV is an order of magnitude more effective than either alone.

The same system safeguards should be employed as with hydrogen peroxide oxidation.

UV Radiation

Published information indicates that UV radiation promotes a number of reactions in the process of the destruction of organic compounds in water. While it is impossible to predict all the organic oxidation reactions that may take place, the following is a representative equation:



The UV oxidation reactions that do occur are referred to as *photolysis* and are defined as a breakdown of molecular bonds. (Other photochemical effects of UV light are the destruction or reduction of ozone, TOC, pesticides and chlorine or chloramine.) The following are some of the specific reactions mentioned in the literature:

1. UV radiation at a 185 nm wavelength reacts with dissolved oxygen in water to produce ozone. The ozone reacts directly with organic compounds, reducing them to primarily carbon dioxide and water.
2. 185 nm UV radiation also produces hydroxyl radicals by lysing the water molecule. This is why substantial TOC reductions have been observed in water containing little or no measurable dissolved oxygen.
3. During the 185 nm reaction with water and dissolved oxygen, hydrogen peroxide is formed during the hydroxyl radical production. The peroxide then reacts with the 254 nm UV radiation again to produce the hydroxyl radical.
4. The UV radiation alone will cause the disassociation of organic compounds.

Most reactions end with the production of hydroxyl free radicals (OH^\cdot), which will oxidize organic impurities in water to carbon dioxide, other gasses, ionized organic species.

Again, care must be used in the design and startup of 185>254 systems. Water exiting the UV chamber may also contain ozone, hydrogen peroxide and/or organic carbon that have not been fully oxidized. Therefore, the water exiting the reaction must be treated to remove these contaminants prior to contacting ion exchange resin. Ozone and hydrogen peroxide can damage ion exchange resins resulting in an increase in TOC and a reduction in capacity. A properly sized 254 nm UV polisher will usually accomplish this task. Even so, safeguards similar to those of the peroxide>254 systems should be employed with at least a controlling ORP monitor on the outlet.

Ultraviolet (UV) Reaction Chamber Design

Not all UV sterilizers are created equal. The proximity requirements of a 185 nm and a 254 nm chamber are quite different.

254 nm vs. 185 nm Radiation

While 254 nm radiation can travel effectively through water for almost a meter, 185 nm radiation, because of its interaction with water molecules, loses much of its strength after several centimeters. Because of the rapid loss of 185 nm radiation over distance in water, the reaction chamber volume of a 185 nm UV oxidizer must be much smaller with respect to the lamps and quartz sleeves, than that of a 254 nm UV sterilizer.

No matter what the geometry of the reaction chamber, UV systems used for both 185 nm and 254 nm radiation need to have the following features:

- A highly reflective reaction vessel. The best reaction vessels are constructed of electro polished 316L stainless steel that are designed for the efficient transfer of radiation into the water. A PVC or other plastic UV reaction chamber can be counter-productive. Effective UV radiation will attack plastic, frequently increasing the TOC load.
- High output, low-pressure UV lamps are the best choice for producing radiation at 254 or 185 nm wavelengths. Medium and high-pressure UV lamps emit most of their radiation at higher wavelengths, and are less suitable for TOC work.
- The reaction chamber should be designed for easy replacement of the UV lamps, since the lamps must be changed routinely, every 6-9 months.
- High quality quartz sleeves that are resistant to solarization and allow efficient passage of UV radiation into the reaction vessel. Even high quality quartz will degenerate when exposed to UV radiation. Quartz sleeves should be replaced every couple of years. Better yet, a UV radiation monitor can be mounted on the chamber itself to report the amount of UV radiation actually going through the water.

The ionized substances produced by any of the TOC removal processes above will decrease the quality of high purity water. Depending on the water quality requirement, and the magnitude of the decrease in the water purity, mixed bed ion exchange resins may be required down stream to polish the water back to high resistivity (18.3 Ω M/cm³ for example) by removing the TOC destruction products such as carbon dioxide and any ionized organic compounds.

An Example System For Producing Low TOC Levels:

- Reverse Osmosis Unit w/ pretreatment
- Mixed Bed Deionization
- Cartridge Filtration
- O₃, H₂O₂ injection
- 185 nm UV radiation Chamber
- 254 nm UV radiation Chamber
- Pre-rinsed high purity mixed bed resin
- Sub-micron Filtration

**For More Information Please Call
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Note: Comments and criticisms of this article are solicited.
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