Total Organic Carbon

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Most modern point of use lab water systems are capable of producing ultrapure water with a low background Total Organic Carbon (TOC) level. The systems that produce the lowest TOC levels contain an ultraviolet radiation reaction (UV) chamber designed to destroy organic carbon compounds.
To efficiently destroy unwanted organic compounds in water, the UV reaction system needs to contain a number of important features. First, the system requires a high output UV lamp capable of producing radiation at 254 and 185 nm wavelengths. Second a high quality quartz sleeve that allows efficient passage of the desired radiation wavelengths from the lamp into reaction vessel. Third, the system needs an electro polished 316L stainless steel reaction vessel that is designed so a thin sheet of water passes between the quartz sleeve and inside vessel wall. This optimizes efficient transfer of radiation into the water path.
It is also desirable to have the UV reaction chamber mounted horizontally in the system. Published information indicates that the horizontal configuration is more efficient for destroying organic compounds. This may be due to a more even temperature distribution across the reaction vessel or lamp.

As stated above, a high output UV lamp is important for efficient organic destruction. It is also important to have a high quality quartz sleeve for the UV lamp.
A typical UV reaction chamber has a lamp inside the quartz sleeve. The sleeve protects the lamp from direct contact with water and allows the wanted UV radiation to pass into the water. If low quality quartz sleeve material is used, much of the desired UV radiation may be blocked or absorbed by the quartz. It should also be noted that it is important to change out the quartz sleeve each time that the UV lamp is replaced. Even high quality quartz material will degenerate as exposed to UV radiation. Over time, the quartz will degenerate to a point that most of the UV radiation will not pass through the sleeve. Putting a new UV lamp in an old sleeve wastes the value of the new lamp and the time to replace it.

A number of reactions have been presented regarding how UV radiation promotes the destruction of organic compounds in water. Each reaction ends with the production of hydroxyl free radicals (OH) which oxidize the organic impurities to carbon dioxide and water. One reaction involves the 185 nm wavelength catalytic activity on dissolved oxygen in water that produces ozone. The 254 nm wavelength then reacts with ozone to produce the hydroxyl radicals. During the 185 nm reaction with water and dissolved oxygen, hydrogen peroxide may also be produced as an intermediate during the hydroxyl radical production. The peroxide then reacts with the 254 nm UV radiation to form the radical. It should be noted that peroxide and ozone might also react directly with organic compounds in water to promote destruction of the organic contaminant.

The 185 nm UV radiation can produce hydroxyl radicals by lysing the water molecule. This would explain the TOC reduction observed in water containing little or no measurable dissolved oxygen. Further, exposure to the low wavelength UV radiation may also promote direct disassociation of some organic compounds. Activated carbons and ion exchange resins located down stream can easily remove the dissociated organic compounds.

Ultraviolet reaction vessels are normally located upstream of a final polishing cartridge in lab water systems. This is due to the carbon dioxide and possible intermediate organics and reactants produced in the reaction vessel. The carbon dioxide generated in the reaction vessel will lower the resistivity or increase the conductivity of the water exiting the vessel. There may be 18.2 MΩ × cm water entering the chamber while 10.0 MΩ × cm or less water exits. Therefore, downstream polishing of the UV effluent water is required to bring the water back to 18.2 MΩ × cm quality.

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. Partially destroyed organic carbon from the UV reaction chamber will also affect resin capacity. Therefore, it is important to treat the water exiting the UV reaction vessel with special adsorption and catalytic media to protect the ion exchange resin.

The choice of ion exchange resins used after the UV reaction chamber is also important. Once you have removed the majority of TOC from the treatment scheme, you must avoid putting more TOC back into the system.
Ion exchange resins come in many grades. The most common used in lab systems are nuclear and semiconductor grade high purity mixed bed resins. The semiconductor grade are typically guaranteed to produce 18.0 MΩ × cm specific resistance water with low extractable TOC. Semiconductor resins are specially treated to remove manufacturing byproducts, which can contribute to TOC levels in product water.

Along with the proper choice of post UV reaction vessel media design, it is also very important to have the correct pretreatment media and volume. The correct volume of pretreatment media is as important as the UV reaction vessel design. Most water systems use one or more types of activated carbon in the first media cartridge of a system. In many cases, the volume of the activated carbon in this first cartridge is inadequate to properly treat the incoming feed water. Activated carbons require a certain amount of contact time in order for them to remove contaminants. For most applications the activated carbons are used to remove or reduce chlorine and/or organic compounds. Activated carbons can lose efficiency with low temperature feed water. The pH range of a feed water source can also have a negative effect on activated carbon. Feed water temperatures and pH can fluctuate indefinitely from a single source. Therefore, by providing the largest amount of activated carbon possible in a pretreatment cartridge, the best reduction or removal of feed water TOC and chlorine can be achieved at a given flow rate.

The importance of activated carbon pretreatment volume can be simply demonstrated by comparing identical water purification systems on the same feed water source. The only difference in the systems is the volume of activated carbon in the pretreatment cartridge. Flow rates being equal, TOC measurements are taken before and after a 20-liter draw of purified water. The before TOC data is collected on a re-circulating system. In the system with the larger amount of activated carbon, the TOC level may rise from 2.0 ppb to 5.0 to 6.0 ppb after the draw. The system with less activated carbon may show a TOC level above 20.0 ppb after the draw. The system with the higher volume of activated carbon will provide the best quality water.

Finally, Total Organic Carbon (TOC) analysis of laboratory grade water can be a useful tool to monitor the quality of the water. Total organic carbon analysis provides a generic test of the overall organic carbon content of a system. Although the technique only provides a total organic content, as opposed to a specific organic compound, the method can show trends or alert the user to a potential problem. Problems can arise from feed water system failures or something as simple as a UV lamp needing replacement.

SIEVERS INSTRUMENTS
SIEVERS TOC
SERIAL #1 VERSION 3.14
01/29/01

Acid = 0.20 ml/min
Oxidizer = 0.00 ml/min
UV = ON

TIME	TOC
09:01	0.43 ppb
09:07	0.22 ppb
09:13	0.24 ppb
09:19	0.52 ppb
09:25	0.85 ppb
09:31	1.13 ppb
09:37	1.30 ppb
09:43	1.52 ppb
09:49	1.70 ppb

arium 611 UV/UF with RO Feed
Water to drain for duration of test (48 min).

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