Aquafine

TROJAN technologies

TOTAL ORGANIC CARBON (TOC) REDUCTION IN MICROELECTRONICS

Michael Sasges, Ph.D., P.Eng., Aquafine Corporation, Trojan Technologies

The advantages of synthetic quartz in TOC systems

Introduction

An important step in producing Ultrapure water (UPW) is the removal of total organic carbon (TOC) by using ultraviolet irradiation to oxidize or ionize organic molecules, followed by ion exchange to remove the ions from the water. LED emitters cannot be used for TOC reduction because of their very low efficiency at UV wavelengths, in sharp contrast to their high efficiency in producing visible light. Mercury lamps are the only economical sources of the short wavelengths required for TOC destruction. There are two general types of mercury lamps: medium-pressure and low-pressure lamps. While medium-pressure lamps are more powerful, their higher heat output, shorter lifetimes, and lower efficiency mean that they are not generally preferred for TOC destruction. Low-pressure mercury lamps are ideal for TOC reduction because of their high efficiency at generating two useful emission lines, 185nm and 254nm.

The 185nm emission is critical for efficient TOC degradation. Although some TOC compounds can be degraded through direct photolysis by 254nm photons, most TOC reduction is initiated by photochemistry driven by the absorption of 185nm photons by water itself. These energetic photons photolyze the water molecule, resulting in highly reactive and short-lived OH radicals. These radicals can ionize or otherwise break down most TOC compounds. Therefore, the most important predictor of TOC reduction performance is the amount of 185nm light reaching the water.

The high energy associated with the short 185nm wavelength is strongly absorbed by many grades of quartz (fused silica). When these photons are absorbed, the energy can damage the quartz, reducing the transparency. This in turn blocks more of the 185nm photons, accelerating the rate of damage. This absorption takes place at two locations: the lamp wall, and the quartz sleeve that separates the lamp from the water.

Synthetic Quartz

There are many grades of quartz available, and these may be categorized as "natural" or "synthetic", based on the source of the raw materials used. Natural quartz is derived from naturally-occurring raw materials, primarily silica sand. By contrast, synthetic quartz is derived from purer raw materials such as $SiCl_4$. There are many additional details relevant to producing high quality quartz, such as the choice of heat source (electrical vs. combustion), and the post-production heat treatment, but in general synthetic quartz has superior transmission of the critical 185nm wavelength, improving TOC destruction. As will be seen below, the advantage of the synthetic quartz becomes greater with operating time, as the natural quartz is degraded by the short wavelength.

Initial Performance

The higher transmission of 185nm photons by synthetic quartz lamps and sleeves leads to an immediate performance advantage in TOC reduction. **Figure 1** shows the relative rate of reduction of TOC in a reactor. The reactor, lamp driver, and power level are identical for both systems; the only change is the grade of quartz used in the lamp and sleeve. It is clear from this figure that the synthetic lamps and sleeves deliver superior TOC destruction. As the flow rate and associated mixing increase, the benefit of the synthetic quartz increases further.

Lamp Aging

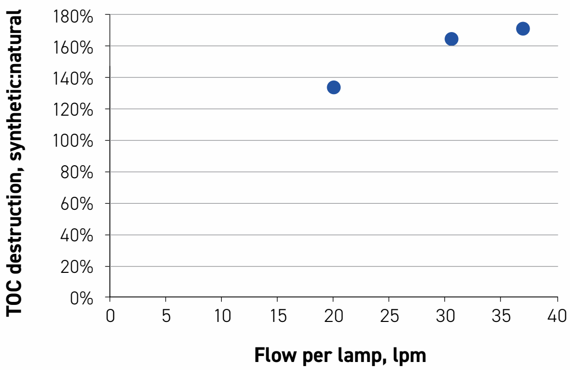
The relative benefit of synthetic quartz increases with operating time, as the output of the synthetic lamp is maintained at a higher level than the natural quartz lamp. In order to assess this factor, 10 lamps of each type were installed in reactors and operated for more than one year. The lamps were periodically removed from the reactor and their output measured at both wavelengths. The following figure shows the measured lamp output of a group of lamps as a function of operating hours.

As can be seen from **Figure 2**, the synthetic lamp maintains most of its initial output at both relevant wavelengths, even after more than one year of operation. By contrast, the 185nm output of the natural quartz lamp, which was already lower than an equivalent synthetic lamp when new, has dropped below 60% after less than one year. As a result, the synthetic lamps maintain far superior TOC performance compared to the natural quartz lamps.

This long-term benefit can be seen clearly by taking the ratio of the output of the synthetic lamp to that of the natural quartz lamp. As can be seen in **Figure 3**, the 185nm output of the synthetic quartz lamp begins at about 120% that of the natural quartz lamp, and due to the lower drop in the synthetic lamp the relative output is about 180% that of the natural quartz lamp after one year.

Since reactor sizing must be based on the end-of-life operating condition, this lamp aging factor allows the use of fewer synthetic quartz lamps to achieve the same performance after one year.

Figure 1: Percent TOC destruction vs. flow, Synthetic:natural.



Aquafine®

Sleeve Aging

The ultraviolet produced by the lamp must pass through a quartz sleeve to reach the water. The transparency of the sleeve drops with operating time as damage from the UV accumulates. To assess this factor, 10 sleeves of each type (synthetic and natural) were installed in reactors and operated with the corresponding lamp type. The sleeves were removed from the reactors periodically and measured using a spectrophotometer. **Figure 4** shows the measured transparency of the sleeves that were operated in a reactor for more than a year.

It can be seen that the synthetic sleeves maintained more than 85% of their throughput (transmittance) at both wavelengths even after more than a year of operation. By contrast, the natural quartz sleeves maintained good transmittance at 254nm, but became partially opaque, with throughput dropping below 50% of their initial transmittance at 185nm after one year of operation.

The benefit of synthetic quartz sleeves is even greater when considering the total amount of UV passing through the sleeve. When new, the synthetic sleeve passes more 185nm than the equivalent natural quartz sleeve, and this advantage increases over time as the natural quartz sleeve degrades. In **Figure 5**, the absolute transmittance of the two sleeve types is compared at various time points. When new, the synthetic sleeve is transmitting about 25% more 185nm UV from the lamp to the water. After 12,000h of operation the synthetic quartz sleeve will transmit nearly 2.5 times as much 185nm UV from the lamp to the water. This translates directly to superior TOC destruction performance for the system with synthetic sleeves and allows the use of fewer lamps to achieve a given level of performance.

Conclusion:

The performance of a UV-based TOC reduction system can be greatly affected by the choice of quartz material used in the lamps and sleeves. The use of synthetic lamps and sleeves can result in energy savings over the entire operating life, as well as reducing the number of lamps and sleeves that must be replaced, with resulting reduction in downtime and labor required for maintenance.

High quality synthetic quartz can result in significant decreases in required system size and power for TOC reduction.

Figure 2: Lamp output vs. operating hours, relative to new.

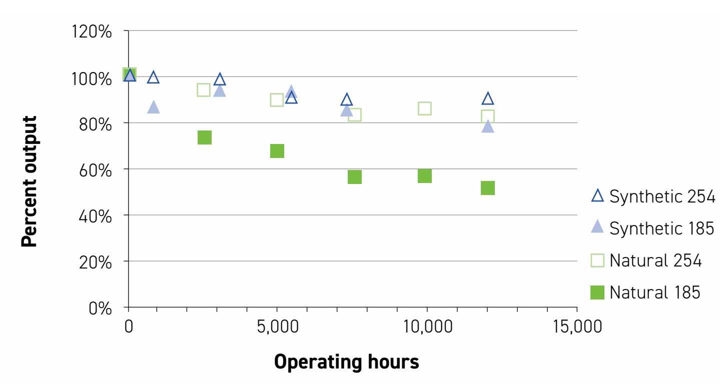


Figure 3: 185nm output of synthetic quartz lamp relative to that of a natural quartz lamp.

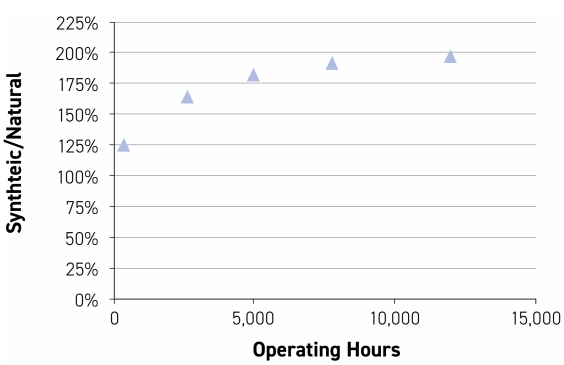


Figure 4: Sleeve throughput relative to new, for synthetic and natural quartz sleeves.

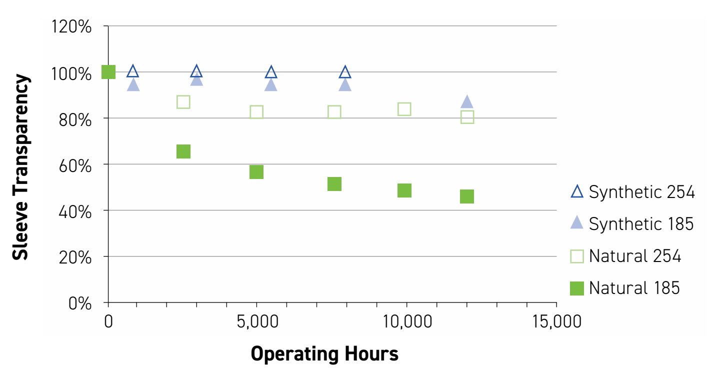
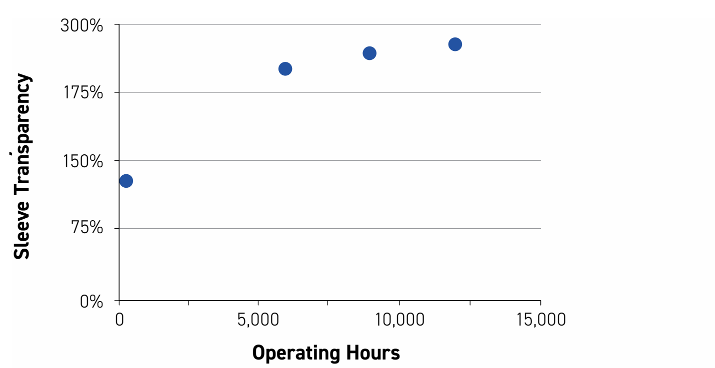


Figure 5: 185nm transmittance of Synthetic sleeve vs. Natural sleeve.



To learn more about the brands and affiliates of Trojan Technologies, please visit www.trojantechnologies.com

TROJAN technologies®