

Let Your UV Light Shine

Research scientists overcome drinking water industry assumptions that UV radiation is ineffective for fighting Cryptosporidium and develop a UV treatment to battle the potentially deadly pathogen

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The enormity of the problem facing the drinking water industry first surfaced in the United States in 1993, when *Cryptosporidium*, a single-celled parasite living in the intestines of warm-blooded animals, made its way into the drinking water in Milwaukee, leaving 403,000 people sick and 104 people dead.

Cryptosporidium, which causes severe diarrhea, cramping and nausea in healthy adults and can be fatal for people with weak immune systems, has no cure and drinking water experts quickly began scrambling for a water treatment method that could effectively destroy the dangerous pathogen before it made its way into people's homes.

Since the deadly Milwaukee outbreak, there have been at least 20 more *Cryptosporidium* outbreaks in North America, leading to stringent new water treatment rules by the U.S. Environmental Protection Agency (EPA) and intensifying the need for a comprehensive, cost-effective solution.

Grappling with the Problem

As far as the drinking water industry was concerned, there was no good answer for protecting drinking water from *Cryptosporidium*.

Chlorine was found to be ineffective at battling the pathogen unless it was applied at such toxic levels that it became dangerous for humans. Notwithstanding the long use of ultraviolet (UV) radiation for treating various bacteria in drinking water, the industry also believed that UV radiation was ineffective for fighting *Cryptosporidium*. Scientists had found that UV doses for *Cryptosporidium* oocysts needed to be a hundred times higher than required for other microbes. Most bacteria require 10 millijoules per centimeter squared (mJ/cm^2) to achieve 4-log (99.99 percent) inactivation; some viruses 30 mJ/cm^2 to 50 mJ/cm^2 ; and some spores several hundred mJ/cm^2 . This was nowhere near the 8000 mJ/cm^2 said to have been required for UV inactivation of *Cryptosporidium* oocysts. Consequently, industry research done prior to 1996 concluded that the only way to effectively eliminate the threat of *Cryptosporidium* using UV was to kill the pathogen. And to do so, it was thought that doses higher than 8000 mJ/cm^2 would have to be used, making UV treatment economically unfeasible.

Left with little choice, the drinking water industry started turning toward ozone and filtration technologies. Though effective at inactivating the organism, these treatments were also cost prohibitive -- as much as 10 times the cost of traditional UV technology. What's more, ozonation left behind hard-to-treat byproducts.

Research Breakthrough

The research scientists at Calgon Carbon questioned the industry assumptions regarding the use of UV radiation to inactivate the oocysts of cryptosporidium. The researchers, knowing that the peak of deoxyribonucleic acid (DNA) adsorption of Cryptosporidium is at 260 nanometers (nm), theorized that protein of the oocyst did not adsorb well in the 200 nm to 240 nm range and, thus, believed that they could effect the oocysts with UV.

The issue now facing the Calgon Carbon scientists was how to effectively demonstrate their new theory that *Cryptosporidium* could be effectively combated using low UV dosages.

In the fall of 1996, Calgon Carbon decided to test its new theory applying the commonly used *in-vitro* methods of excystation and vital dyes as well as *in-vitro* infectivity to measure the impact of a disinfectant in fracturing or destroying the oocyst shells, thereby ending all metabolic activity.

Upon reviewing the test data, especially the *in-vitro* data, the team at Calgon Carbon knew they had discovered a revolutionary new method for combating *Cryptosporidium*. According to their test data, only low dosages of UV were required to inactivate the sporozoites. This made UV radiation by far the most cost-effective treatment method available for *Cryptosporidium*, which could translate into billions of dollars in savings for the water drinking industry.

External Evaluation Testing

Calgon Carbon knew external testing was needed to verify its breakthrough discovery, and in late 1997, the company assigned the testing program to Clancy Environmental Consulting (CEC). The firm conducted mouse infectivity studies, in which *Cryptosporidium* oocysts were exposed to UV radiation, collected and then fed to mice. The intestines of the mice were then microscopically examined to determine if *Cryptosporidium* sporozoites had multiplied and infected.

The application of medium-pressure UV light (200 nm to 300 nm) was investigated at bench scale. The lowest dosage chosen for the Calgon Carbon-sponsored testing was 40 mJ/cm².

The bench-scale results in late 1997 and early 1998 stunned the CEC investigators. The *in-vitro* methods still pointed to high UV doses to "kill" (fracture oocyst outer shells). But infectivity testing showed much lower doses were required to prevent replication, as measured by 4-log (99.99 percent) inactivation. The lowest dose tested had resulted in no mice showing symptoms of infection, confirming Calgon Carbon's contention that *in-vitro* assay methods massively overstated the dose required to effectively eliminate the threat posed by *Cryptosporidium*.

The low doses were shown to dimerize, or cross-link thymines in the *Cryptosporidium* DNA double-stranded helix, disrupting the process of forming new DNA, which requires complete separation of the two strands. With its DNA thus altered, the organism was still metabolically alive in terms of intact membrane or outer shell, as well as all other cell functions. However, as Calgon Carbon's initial testing had demonstrated, the organism could not reproduce, and thus was effectively rendered harmless.

Verification Testing

The team at Calgon Carbon realized that experience on a larger scale was still needed to obtain critical design information, as well as market credibility, and set to work on the next phase of testing.

Under the auspices of EPA's new Environmental Technology Verification (ETV) program, run by the National Sanitation Foundation (NSF), Calgon Carbon built and installed a 200-gpm pilot unit and became the first company to be approved for an ETV certification project.

Cartwright, Olsen & Associates LLC, a third-party consulting firm, carefully controlled the effort. The firm oversaw the development of the evaluation protocol and maintained all controls, including supervision of the experimentation and certification of the results. The 100-page evaluation protocol book was peer-reviewed prior to beginning the actual testing. Pilot plant testing, following manufacturing and installation, began in February 1998.

Like the investigators at CEC, the ETV investigators were astounded with the subsequent results, which showed that at the lowest UV dose applied, 19 mJ/cm², only one in 25 mice was infected and that, at all other doses, no mice showed symptoms. The pilot results confirmed the bench results: UV radiation inactivated the oocysts, and did so at incredibly low doses. Investigators in several different laboratories have since confirmed these results.

In part because of the verification testing program conducted with Calgon Carbon, EPA quickly became interested in UV technology, and created a UV sub-workgroup to report to the Federal Advisory Committee on Microbial-Disinfection By-Products on issues and costs related to UV disinfection of drinking water.

Patentable Technology

Based on laboratory results, later reinforced by the pilot plant testing, Calgon Carbon filed a patent application in May 1998. Calgon Carbon's Sentinel™ UV Disinfection System, designed specifically for the drinking water industry, was launched at the AWWA show the following month.

In October, 2000, the U.S. Patent office granted Calgon Carbon a patent covering its inactivation treatment process, with the abstract stating "a method for prevention of *Cryptosporidium* oocysts and similar organisms in water by irradiating the water with ultraviolet light in a range of 200 nm to 300 nm in doses of about 10 mJ/cm² to 175 mJ/cm²." In March 2002, the Canadian government also issued Calgon Carbon a Notice of Patent Allowance.

In early 2003, Calgon Carbon was granted patents covering its inactivation treatment process in New Zealand and The Netherlands. In May, 2003, Calgon Carbon was granted its second U.S. patent for preventing infection from *Cryptosporidium* and *Giardia*.

Reactor Validation

With the testing and verification of Calgon Carbon's breakthrough inactivation method complete, research efforts have been focused on UV-reactor validation to ensure water plant operators of continuously effective levels of UV radiation.

Germany's Association for Gas and Water (DVGW)¹ has conducted research concluding that: 1) the required UV dose for 4-log bacteria and virus inactivation is 40 mJ/ cm²; 2) no significant byproducts or water quality changes occur with this UV dose; and 3) a reactor certification laboratory should be created to certify large-scale UV reactors under uniform and worst-case conditions. The certification process covers support documentation for the UV lamp that includes spectral characteristics, quartz sleeve transmission and sensor parameters; verification of UV sensors with a reference sensor; on-line command and control; and a challenge test to measure inactivation of a challenge microbe achieved by the reactor at full flow rates.

The final information required for state regulators to grant disinfection credits for UV technologies is operational data. Calgon Carbon has developed detailed guidelines and computational fluid dynamics (CFD) modeling for design engineering issues. Control and command features, system maintenance and operator training are based on Calgon Carbon's experience with over 250 medium pressure UV installations treating municipal wastewater, contaminated groundwater, industrial wastewater and drinking water.

Summary

Prior to Calgon Carbon Corp.'s discovery, application of UV for disinfection of drinking water to provide complete control of bacteria, viruses and protozoa was not considered an economically viable technology. Many municipalities were considering expensive filtration and ozone technologies that would have cost substantially more than Sentinel UV technology. Since then, the industry has been able to take advantage of UV designs, providing for more efficient and affordable multiple-barrier systems.

Calgon Carbon's innovative research and discovery, and progressive commercialization in partnership with the municipal water industry, has generated a new method to protect against *Cryptosporidium* in a cost-effective manner. Calgon Carbon Corp. has been supporting the consulting engineering and water treatment industry with ongoing, CFD-enhanced designs for new Sentinel systems to meet the growing demand.

Reference

1. DVGW Arbeitsblatt W 294(1997) UV-desinfektionsanlagen für die trinkwasser-versorgung-Anforderungen und prüfung. Bonn, Germany.

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