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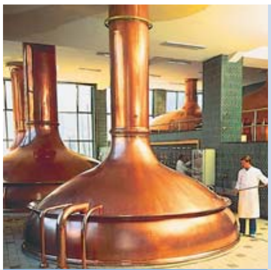

Preprint

Old technology with a new twist

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UV DISINFECTION OF WATER | Is disinfecting water a question of philosophy? The disinfecting power of UV rays has been known for over 100 years. As far back as 1903, the Nobel Prize for Medicine was awarded to Niels Finsen for his work in eliminating tuberculosis pathogens with UV rays [1]. UV lamps also quickly found a niche in the beverage industry and served as a means for disinfection, especially of fresh water. This, however, poses the question of why there has been a new wave of interest in UV disinfection of water – after all, the trend had been moving towards chemical and/or electrochemical disinfection methods for some years.

IN THE LAST COUPLE OF YEARS, a trend towards UV treatment of water has emerged. Why has there been a change of heart again? Was it not always argued that the efficacy of this technology was questionable, especially when the water contains particulate matter causing shadows to be produced? What became of the arguments against UV lamps and their high levels of electrical power consumption?

The reasons behind the emerging trend towards UV technology are probably to be found in the following:

Primarily, classical chemical disinfection processes adversely affect the flavor of many beverages on the market today. For example, water is added during the final stage in the production of lemon-flavored soft drinks. If this water was disinfected using a chlorine-based agent, an off-flavor results from time to time. Moreover, the beverage producers themselves are also striving to simplify processes and to create a safer working environment. Furthermore meanwhile the analytical possibilities to proof residues of chemical treatment are much better than years before and due to regulations by law, many producers prefer other ways of water disinfection than the chemical ones. UV treatment offers an effective means of disinfection, as will be shown below.

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UV disinfection – advantages and disadvantages

The disadvantages associated with the UV disinfection of water are a recurring theme in research publications.

For example, some publications describe the ability of microorganisms to regenerate after their DNA was damaged by UV radiation [2-3]. The authors report that although the microorganisms sustained damage to their DNA through exposure to UV light from low pressure lamps, in many cases the microorganisms were able to repair this damage. As a consequence, the lines in water supply network became contaminated with biofilms, which eventually led to serious problems related to the microbiological safety of the products. The explanation for this can be found in the peak wavelength of 254 nm, which is specific to low pressure lamps and is coincidentally in close proximity to the absorption maximum of 265 nm for nucleic acids. Therefore, low pressure lamps primarily damage the nucleic acids or DNA, but not necessarily other microorganism cell components.

However, in the meantime, medium pressure lamps are more common in beverage industry applications. Medium pressure lamps emit polychromatic UV light at wavelengths between 185 and 400 nm, allowing them to cover the absorption maximum of nucleic acids (265 nm) as well as the maxima of most proteins (280 nm). This causes damage to many proteins, particularly to

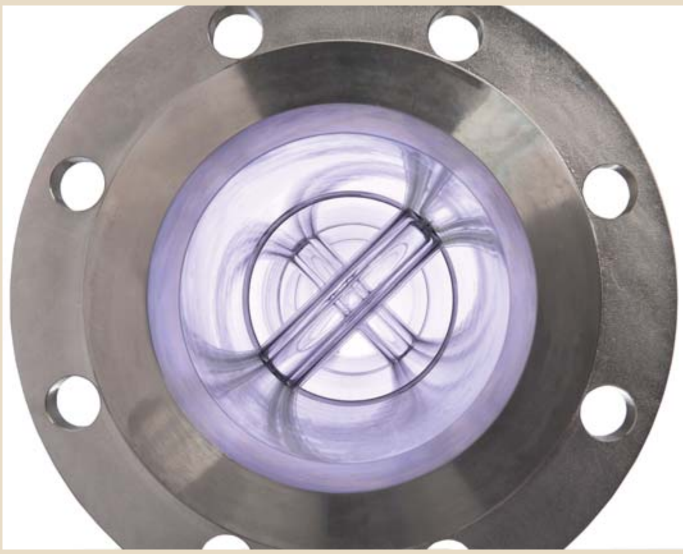

Fig. 1 Quarz tube

those which contain aromatic amino acids (tryptophan, tyrosine and phenylalanine). The microorganisms in the water are damaged at the DNA level as well as the protein level, causing permanent damage to their enzyme systems. A reactivation of microorganisms exposed to this type of UV radiation has not been observed to date, as is confirmed in the research of Zimmer and Oguma mentioned above. For this reason, medium pressure UV lamps are clearly preferable for water disinfection applications.

Also mentioned in the literature, a further disadvantage of UV disinfection of water is related to the presence of absorbing substances in water, such as humic acid, which negatively influences UV transmission. Humic acid is present in almost all water, regardless of whether it is collected from a surface reservoir or underground. An additional critique found in the same source is that the UV lamps lose their intensity over time [4].

Both arguments are understandable; however, an innovative unit presented in this study and used today for UV water disinfection virtually negates these objections, because two UV sensors provide automatic monitoring of the process. One sensor is mounted in front of the lamp to detect the intensity of the UV rays, which is displayed directly on the controller interface. Any loss of intensity through the weakening of the lamp is immediately detected. A second detector is positioned some distance away from the lamp and measures the intensity of the UV rays after they have been transmitted through the water being treated along a defined path (i.e. UV transmission, UVT). UVT value in combination with the intensity of the light, both measured in real time, allows on-line UV-dose measurement and the ability of the lamp's intensity to be adjusted accordingly.

The concept of shadows caused by particles in the water is also often mentioned in conjunction with the transmission of UV rays in water disinfection. If microorganisms are present on the surface of particles as they pass through the reactor chamber during treatment, it is theoretically possible that microorganisms located on the surface of the particle opposite of the UV lamp will either receive no exposure to the UV rays or only an insufficient dose. Some manufacturers try to overcome the issue by designing systems based on long flow patterns and multiple, relatively long lamps aligned with the direction of water flow, trying to expose the particles to the UV rays from several directions as they flow past. Another manufacturer has chosen to utilize a different type of technology, which will be described in more detail in the latter part of this text.

Fig. 2 RZ-163 model

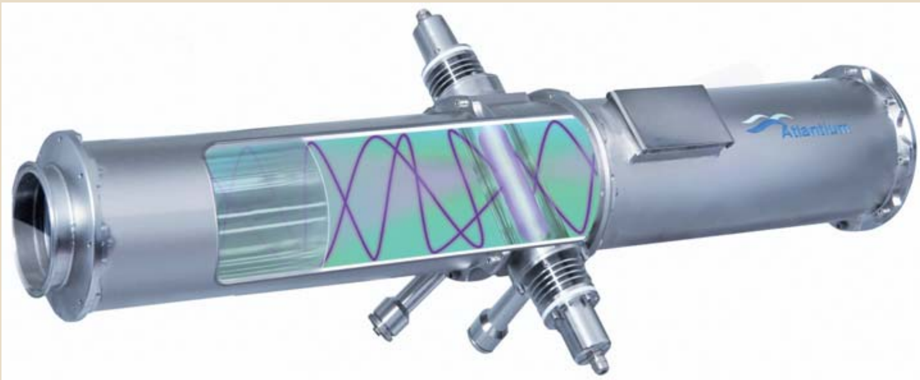

Fig. 3 Schematic of UV rays during disinfection

An additional disadvantage of water disinfection with UV is the ongoing cost of operation primarily due to replacing lamps which no longer deliver the required intensity. It is less expensive to operate systems outfitted with medium pressure lamps. The specific electricity consumption for systems utilizing medium pressure lamps is approximately 0.04 kWh/m³ of water treated.

The absence of a sustained disinfection effect after water treatment, i. e. the lack of residual disinfection downstream from the UV lamp is certainly a disadvantage that cannot be ignored. For this reason, manufacturers frequently install multiple UV treatment systems in critical production areas where a renewed disinfection is necessary, for example, upstream from blenders used in high gravity processes. Whether this type of additional investment makes sense financially must be evaluated on a case-by-case basis. Numerous facilities have decided to adopt this concept; therefore, it can be assumed that this additional investment is reasonable for some applications. In light of these challenges, routine cleaning and disinfection of the on-site network of water supply lines takes on special importance.

It's all in the reflection!

One of the modern medium pressure systems enjoying increasing popularity in the beverage production industry is the Hydro-Optical Disinfection system manufactured by Atlantium Technologies Ltd., Israel.

The system consists of a quartz pipe in a stainless steel housing (fig. 2). The water to be disinfected flows through this quartz pipe, which serves as the disinfection chamber. Another quartz tube mounted perpendicular to the main quartz disinfection chamber contains a medium pressure UV lamp (fig. 1). Multiple tubes each containing a UV lamp can be integrated depending on the model and flow rate.

The following information pertains only to the RZ 163 tested model, which was equipped with only one lamp (fig. 4). This lamp draws 1.7 kW of electrical power at full load. Depending on the quality of the water, the unit provides 120 mJ/cm² [5] and treats 50 m³/h of typical municipal water

MICROBIOLOGICAL ANALYSIS RESULTS

Microorganism	Flow rate (m^3/h)	Lamp intensity (%)	UVT (%)	Calculated dose (mJ/cm^2)	Volume of sample analyzed (ml)	Colony count at inlet (CFU/l)	Colony count at outlet (CFU/l)	Log reduction
Lactobacillus casei	49.5	100	92.4	99.5	1000	2500	0	3.4
Escherichia coli	49.5	100	94.9	143.1	1000	2.2×10^7	0	7.1
Saccharomyces cerevisiae	49.5	100	94.15	127.1	1000	2.5×10^6	0	6.4

Table 1

(UVT ≈ 95 %) or even up to 100 m^3/h of purified RO water (UVT ≥ 99 %) while operating at full load. The quartz tube for the water has a diameter of 163 mm.

It is critical that the lamp in the quartz tube be positioned perpendicular to the direction of water flow. The quartz walls of the tube continuously reflect the UV rays back into the water, using the same physical principles used in fiber optics. Essentially, the quartz tube act as optical fiber and capturing the UV (fig. 3). This does not only effectively prevent shadows and low dose tracks, the reflection also ensures that the UV rays come into contact with the entire surface of any particles that may be present. Furthermore, the effectiveness of the lamp is also markedly increased because the path of the rays is significantly extended through the water.

An ultrasonic cleaning unit is integrated and keeps the inside of the quartz tube clean and deters formation of deposits and prevents the corresponding reduction in ray intensity (fig. 4).

The system features a self-monitoring control unit, as described above. The sensor mounted directly in front of the UV lamp constantly monitors lamp intensity. Another sensor located in the reactor chamber measures the UV transmission capacity of the water in conjunction with lamp intensity sensor. Using both of these data inputs, the system on-line computes the actual UV dose delivered to the water and tracks it to keep it within the operational requirements

This system has an automatic mode of operation which adjusts the lamp power automatically to compensate for variations in transmission capacity or changes in flow rate, which in turn helps conserve electricity while ensuring the appropriate disinfection level.

As part of the test series conducted for validation of this system, experiments were conducted using *Escherichia coli*, *Saccharomyces cerevisiae carlsbergensis* as well as *Lactobacillus casei*. These three microorganisms are of special interest for breweries. For the experiments, suspensions of each microorganism were prepared and continuously dosed into the stream of water entering the disinfection unit. To guarantee reproducible starting conditions for testing, mineral salts were removed from the water by reverse osmosis. Subsequently, NaCl was added to the water to a concentration of 0.9 percent so that the microorganisms would not be affected by the high osmotic pressure. To simulate the normal concentration of UV absorbing substances in the water, lignin sulfonate was added until the UV transmission reached approximately 94 percent, which corresponds approximately to the typical value for municipal drinking water. In order to ensure that the water did not contain any other living microorganisms, the water was disinfected by circulating it through the disinfection unit for approximately 30 min prior to the addition of the test microorganisms.

Fig. 4 Tested RZ-163 system model including sensor placement and ultrasound cleaning

After disinfection, water samples were collected and analyzed for total cell count. For all three test runs, it was proven that the water was sterile before the tests commenced.

During each test run, three samples were collected simultaneously at the inlet and outlet of the unit at 25 second intervals. The cell count was determined after membrane filtration and incubation on selective media. The mean values of the three analysis samples collected for each microorganism are listed in table 1.

The analysis results show the effectiveness of the system against all three microorganisms. It can be assumed that practically complete disinfection of the water was achieved.

Example of real-life application

For the past several months, Türk Tuborg, Izmir (fig. 5) has been testing two Atlantium units under real production conditions. One unit is located downstream from the reverse osmosis equipment. After UV treatment is complete, the disinfected water is routed to the cold water storage tank.

The second unit is located downstream from the water de-aeration equipment to disinfect the water used for blending.

Prior to the installation of the Atlantium units, no measures were taken to disinfect water at the brewery. The decision to begin disinfecting water was prompted by the antiquated water supply network and fluctuations in the quality of the incoming water. In part, Atlantium was chosen due to a very positive referral from a trusted brewery. Additionally, UV technology offers the opportunity to treat water without using chemicals. In the past, up to 80 CFU/ml were recorded for each water sample analyzed. Although this lies within the allowable range stipulated by the regulations governing drinking water in Germany, the water was not deemed to be of acceptable quality by the brewery. Since the Atlantium units have been in operation, no more than 2 - 3 CFU/ml have been found in the samples collected. This alone has convinced the brewery of the effectiveness of the system.

Concluding assessment

UV disinfection of water represents a safe, inexpensive choice for water disinfection in beverage production facilities. The advantages of this system, which functions on a purely physical basis, include low operating costs, no modification of product flavor and employee safety. The disadvantage posed by the absence of a residual disinfection effect after treatment can be addressed by the appropriate cleaning and disinfection of the lines in the water supply network or through the utilization of multiple UV units.

After reviewing modern UV disinfection systems, illustrated using the HOD RZ 163 unit manufactured by Atlantium Ltd. as an example, UV technology now represents a viable option for production facilities to eliminate the majority of microbiological contaminants in their water supply in a manner that is both safe and automatically monitored continuously. ■

Fig. 5
Türk Tuborg brewery, Izmir

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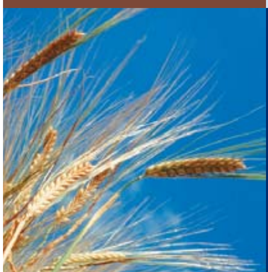

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