White paper discussion on HOD™ (Hydro-Optic Disinfection) UV for microbiological control and chlorine replacement

By Marc J. Scanlon, Senior Technical Sales Manager Atlantium Technologies | August 1, 2022

The following information is from a compilation of Beverage Company Water Treatment Practices:

Historically Approved Water Treatment Processes

The following processes have been historically used in various combinations to satisfy the multiple barrier treatment approach for water treatment at a major beverage Company. The information provided indicates reasons that the named process might be selected as well as general information on potential limitations of the process. Any process selection should be made based on a thorough understanding of the water quality to be treated and the water quality goal of the particular treatment process. Note that the order of these processes in this document is not an indication of any required order in a facility's water room.

In general, the types of processes can be separated into three categories:

- Disinfection processes
- Enhanced filtration processes
- Processes to address other specific water quality characteristics

Disinfection Processes

Disinfection is provided to ensure that pathogenic microorganisms in water are inactivated or killed, and that potential spoilage organisms are controlled. Disinfection processes are used even if ultrafiltration, nanofiltration and reverse osmosis membrane processes which are effective processes for removing microorganisms are used because occasionally tiny breaches in the membrane material or gaskets could allow passage of microorganisms. No physical removal process is ever 100% effective for microorganism control.
Disinfection processes that are the most commonly used in the system are chlorine disinfection, ultraviolet disinfection and ozone disinfection.

Chlorine

Chlorination is the most commonly used form of disinfection for the system. Chlorine processes are frequently used because they offer the assurance of an observable residual chlorine concentration measured after a known contact time in the water. The effectiveness of chlorine residual concentrations and contact times for various microorganisms is extremely well documented in water industry literature.

The chemicals used for chlorine disinfection are typically calcium hypochlorite or sodium hypochlorite. Chlorine gas has occasionally been used by facilities but has many operational environmental health and safety concerns, so usage is discouraged.
Example chlorine introduction processes include:

- Bulk calcium or sodium hypochlorite solutions (limitations: sodium hypochlorite may add minimal sodium concentration to the water; both types of hypochlorite solutions may add excessive chlorate concentrations to the treated water if the solutions are not managed correctly)
- On-site production of calcium hypochlorite solution from a pellet dissolution system (example: Accutab systems)
- On-site production of hypochlorous acid solutions (example: Prominent Dulcolyse – very low addition of chlorate)

Any of these types of systems will add enough residual chlorine to the water to provide effective disinfection for virus and pathogenic bacteria such as coliform if the contact time between the chlorine residual and the water is long enough. The effectiveness of the process is dependent on water temperature, pH, time of the contact between the chlorine residual and the monitored residual at the outlet of the holding time. Complex tables exist that describe these relationships. Rather than requiring facilities to interpret the tables three acceptable scenarios have been identified for the system for using chlorination disinfection. These options are based on the measured free chlorine residual and are independent of the source of the chlorination chemical.

No combination of chlorine residual concentration and contact time appropriate for our manufacturing facilities would provide adequate protection from Cryptosporidium or Giardia. Therefore, either a physical removal process or ultraviolet disinfection is necessary if there is a risk of Cryptosporidium or Giardia in the incoming water.

Option 1

Free chlorine residual measured after the disinfection holding tank or before the GAC is greater than 1 ppm. The time in the holding tank needs to be at least 30 minutes.
Please note the following: the chemical treatment can be done only in the pretreatment since it needs to be taken out by GAC which adds micro load (Atlantium Comment).

Option 2

The BU can work with the facility to validate free chlorine residual concentrations less than 1 ppm by performing calculations to demonstrate the minimum chlorine mass-time/L is >6.0 mg-min/L according to this process:
Demonstrate chlorine contact time (in minutes) with a physical tracer test or calculate based on the tank capacity divided by the average system flow rate, multiplied by a baffling factor of 0.2. When this chlorine contact time is multiplied by the chlorine residual, the resultant must be greater than 6.0 mg-min/L.
This is essentially allowing a complete evaluation of how the water treatment system functions and using the water industry tables to determine what level of protection is provided based on actual operational conditions.

Option 3

Free chlorine residual greater than 0.5 ppm for incoming water from a municipal supply can be acceptable for chlorine disinfection under the following conditions:

- The free chlorine concentration in the incoming water is continuously monitored with an in-line monitor
- Manually record and trend data from visual examination of the in-line monitor display every 4 hours
- The daily average free chlorine concentration is 0.8 ppm or greater
- The continuous in-line monitor alarms and/or stops the process when the free chlorine concentration of the incoming water is below 0.5 ppm
- The incoming water total count is less than 250 cfu/mL and is monitored weekly
- Incoming water coliforms are not detected and are monitored weekly
- Stand-by supplemental disinfection system is available

NOTE:
Although there is not a specified maximum free chlorine residual limit, a concentration greater than 3 ppm coming out of disinfection storage should not be necessary. Higher free chlorine residuals can reduce carbon life and increase disinfection by-product formation. Not typically acceptable: If there is no free chlorine residual present, but there is total chlorine the incoming water has chloramines, or the addition of chlorination at the facility has created chloramines.
Chloramine residual measured as total chlorine residual is not generally an acceptable chlorine disinfection alternative. If the incoming water has total chlorine residual (chloramines) greater than 0.5 mg/L, but has a free chlorine residual of 0.5 mg/L or less

- Chlorinate to break-point to achieve and maintain an acceptable free chlorine residual, or **use a different approved disinfection technology instead of a chlorination process**

Ultraviolet (UV) Light Disinfection

(wavelengths of 200 – 320 nanometers (nm)) that inactivates microorganisms such as bacteria, protozoa, viruses, algae, yeasts, and molds. Different wavelengths penetrate cell walls and alters cell proteins or rearrange the genetic code in the nucleic acids. Altering the cell's code alters DNA so that the organism can no longer replicate and therefore, is no longer infectious. Unfortunately, although the organism may not be able to reproduce and therefore not show up on a plate count, the microorganism might still be observed in the faster PCR microorganism swab test methods.

Different organisms are susceptible to slightly different wavelengths, but UV system design and sizing for dose calculations is based on the measurement of ultraviolet light penetrating the water at UV 254 nm. Therefore, the sizing is dependent on how easily the UV light can pass through the water to reach the potential organisms which is called the ultraviolet transmittance (UVT), how long the contact time is that the light penetrates the water (function of system hydraulics, flow pattern, length of lamp, flow rate), and the intensity the lamps can produce at the 254 nm wavelength.

UV systems are either validated externally by a 3rd Party or they are non-validated. Some water treatment system sequences require a validated unit while other combinations can allow use of a non-validated unit.

- Validated units are an assurance that the unit will provide the stated required dose to all the water that passes through the UV system. Installing a 3rd Party validated unit provides assurance that the dose required will be delivered to all water treated by the unit
- Non-validated units deliver an average dose meaning some of the water passing through the unit may receive a higher dose while some water may receive a lower dose. Non-validated units do not guarantee that all water will receive the necessary disinfection

UV Dose requirements are based on Table 2. Water Treatment Process Combinations.
Third Party Validation

- The UV system supplier will provide the bottler with a certification letter from an external third party as evidence that the third party validated the UV reactor's disinfection performance at specific operating parameters that can be monitored for validated units. The dose to achieve the required level of inactivation must be indicated in the documentation provided by the manufacturer, and the visually displayed RED should match or exceed that documented required dose.

The validation letter must include:

- Details of validation conditions
- Validation protocol used (USEPA UVDGM, DVGM or ÖNorm as appropriate for the required dose)
- Validation approach (UV intensity set point or calculated dose)
- Validation organism
- Log inactivation obtained for the target organism or reduction equivalent dose (RED) achieved
- Ultraviolet transmission (UVT) and flow envelope at which the system is validated

Production facilities cannot validate UV equipment. UV equipment validation as described above can only be performed by external third-party providers at the time of procurement. Evidence of validation must be provided at the time of procurement.

- A validated UV system requires a germicidal sensor to measure the UV intensity delivered from the lamp array at wavelengths of 250 to 280 nm
- The sensor for intensity measurement must be absolute (for wavelength and angular response of the sensor) and non-operator adjustable Validation approach (UV intensity set point or calculated dose)
- If UVT was required for the validation protocol, the UV system must include an instrument for measuring the UVT or ultraviolet absorbance (UVA) of the water

UV systems are typically designed based on inactivation of a target organism. The selection of the target organism and therefore system dose should be based on the other processes used in combination with the UV system. Overall process sequences that do not provide much physical removal of organisms may require a higher UV dose than a process sequence where UV is used following an RO system that provides a high level of removal.

Use of a third party validated unit has historically been required to ensure that the UV equipment used was produced by a reputable manufacturer of UV equipment. Use of third-party validated equipment for critical disinfection processes is still recommended as best-practice.

Third-party validation of units means that an independent organization (not the manufacturer themselves) has tested the equipment and proven that the system will disinfect the target organism at a certain UV dose under a certain set of operating conditions, such as flow rate, UV transmittance (UVT), UV intensity and lamp power. Because this testing involves introducing a test microorganism, usually the target pathogenic microorganisms or a specific surrogate, into a UV reactor and taking sample counts before and after the reactor, it is not practical or possible to validate the performance of a UV system in a facility setting because those organisms should not be introduced into the facility setting.

There are three validation protocols used in the UV equipment.

A validated system will also include a germicidal sensor that measures the UV intensity delivered from the lamp array at wavelengths of 250 to 280 nm. The sensor for intensity measurement is absolute for wavelength and angular response of the sensor and non-operator adjustable. Additionally, if UVT was required for the validation protocol, the UV system installed must include an instrument for measuring the UVT or ultraviolet absorbance (UVA) of the water to be considered as a validated unit.

Validated doses are referred to as reduction equivalent doses (RED) for a specific named organism.

Although validated units tend to be more costly, they are essentially guaranteed to provide effective disinfection. Non-validated units may not actually deliver the necessary dose equally to all fluid that passes through the vessel housing the UV lamps.

Monitoring and Operational Details for UV Systems

Best practice recommends that UV systems installed after should have digital displays that include the following parameters:

- Real-time RED provided by the unit while operating (calculated value)
- Real-time water flow rate through the unit
- Actual or programmed UVT of the water if required by the validation method
- Measured lamp intensity (measured value)
- Lamp operational hours
- Real-time log inactivation of target organism (calculated)

For systems installed without digital displays, the design criteria for flow rates, UVT, number of lamps, lamp intensity, and warrantied hours for lamp life should be documented and available in the Operations and Maintenance Manual of the UV system, or in a validation letter or report. Acceptable operation in the absence of a digital display can be demonstrated by confirming and documenting that:

- The water flow rate through the unit is less than the design flow rate for the unit; (include as part of the Calibration and Maintenance program)
- The UVT for a weekly grab sample of water (taken while the system is running) is higher than the minimum design UVT when measured according to system conditions (wavelength and cell path length).
- The lamp age for all lamps is within the warranty age for the lamps (maintain records for lamp age and lamp replacements)
- The UV intensity on the germicidal sensor is greater than the minimum required to produce the disinfection doses indicated in Table 1 for treatment process combinations
- The total count following UV meets the specification for treated water

UV Dose Selection Guidance

The level of disinfection protection recommended for a UV system depends on the microbiological risk identified for the water and the specific enhanced filtration or other disinfection process used in combination with the UV system.

For purposes of comparison, the typical goal for comparable municipal drinking water systems in the United States, regardless of the initial source water or the process combinations used, is to provide a minimum of 4-log inactivation or removal of virus; 2-log inactivation or removal of

Cryptosporidium and 2-log inactivation or removal of Giardia. In general, municipal drinking water facilities provide more than those minimums with the process combinations used. Occasionally, when US municipalities can demonstrate that their source water is

microbiologically ‘clean’, municipal drinking water facilities using ground water (well water) are sometimes permitted by regulatory authorities to use treatment that does not consider removal of Cryptosporidium or Giardia, but only requires the 4-log inactivation of virus.

In European countries, drinking water regulations are based on a maximum colony count allowed for E. coliform and Enterococci.

See Table 1 for the level of disinfection protection recommended from a UV system when combined with other treatment options to ensure adequate disinfection if a facility has limited information pertaining to the actual microbiological risk associated with the incoming water.

For process combinations where the goal of the UV system is to provide Cryptosporidium inactivation (typically a 4-log inactivation goal), a certified DVGW W294, ÖNorm-validated unit, or an equivalent US EPA Ultraviolet Disinfection Guidance Manual (UVDGM) validated to provide a 40-mJ/cm^2 dose is acceptable. If a DVGW or Önorm-validated unit was installed without a visual display for dose, the systems should have an alternate visual indication that the UV intensity measured by the intensity sensor is as designed to provide the validated 40-mJ/cm^2 dose. These units will also typically provide 3-log inactivation of Giardia, even if that is not specifically stated in the validation documentation.

Suggested Treatment Scenarios

Example levels of disinfection provided by UV systems based on water treatment process combinations.

If UV is combined with:	Corresponds to a system displayed dose of:
Conventional Chemical Treatment (If no chlorination step in the water treatment process)	Per validation document or a minimum of 100 mJ/cm^2 RED for MP 100 mJ/cm^2 RED for LPHO
In-Line Flocculation with Direct Filtration (If no chlorination step in the water treatment process)	Per validation document or a minimum of 120 mJ/cm^2 RED for MP 186 mJ/cm^2 RED for LPHO
Micro Filtration or Ultrafiltration (If no chlorination step in the water treatment process)	Per validation document or a minimum of 100 mJ/cm^2 RED for MP 100 mJ/cm^2 RED for LPHO
Chlorine disinfection included in the overall treatment Process	Certified DVGW W294 O Norm-validated unit, or 3rd party validated unit recommended Doses stated for above combinations can reduced to 40 mJ/cm^2 dose

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Treated Water Recirculation and Storage

Some facilities store treated water in storage tanks to provide buffer capacity for manufacturing. Treated water may be stored chlorinated or unchlorinated.

If treated water is stored for more than six (6) hours, the water should be recirculated with a UV or stored with a chlorinated residual to ensure the microbiological control.

If the water is stored as chlorinated water, the water should have a chlorine residual of 0.2 to 0.5 ppm free chlorine; and the water will require dechlorination with another GAC system prior to being used as an ingredient.

If stored as unchlorinated treated water, the water should include a UV disinfection using an in-line recirculating system and providing a RED of at least 40 mJ/cm^2 as measured by a germicidal sensor at 250 to 280 nm at the end of the lamp's useful life. A higher dose is also acceptable. If recirculation and UV is used to protect the water, the recommended recirculation rate will produce a turnover rate of one tank volume per hour when the tank is idle (no water demand from production). It will be important to ensure that the recirculation flow is adequate to prevent the water and UV equipment from heating to excessive temperatures during the recirculation period.

The recirculation rate should be based on the facility conditions and validate for effectiveness by demonstrating that the water to production meets the treated water microbiological specifications. **The recommended recirculation rate will produce a turnover rate of one tank volume per hour when the tank is idle (when there is no water demand from production areas).**

Best practice is to provide water storage tanks with clean-in-place (CIP) capability for periodic cleaning and sanitizing. Best practice is also to provide a HEPA filter on the tank vents to prevent potential contamination from microorganisms in the room air when the tank is filling, or water is being pulled from the tank.

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The Risks and Remediations suggested for a typical Beverage Plant:

Risk: Lack of disinfection causes microbiological fouling and scaling of the RO and subsequent biofilm downstream of the RO. This causes increased RO membrane cleaning & maintenance which shortens membrane life. The need and frequency of CIP cycles is increased. This location is post GAC and will suffer from microbial burden from the Carbon Tower and can reduce the frequency of steaming or boiling the carbon due to the disinfection properties of the Atlantium unit.

Remediation: HOD UV system on before each RO to provide 120 mJ/cm^2 dose or higher And corresponding 4-5 log reductions of Pseudomonads, Adenovirus, and other organisms. This will extend membrane life, reduce biofouling in the membrane and downstream and Reduce the amount of membrane cleaning and descaling chemicals used. You will also see some TOC Reduction of the organics by HOD UV treatment.

Risk: Well Silo Water that is stored for more than 8 hours without a chemical residual is at risk. If chlorine is used, you have Disinfection By-Products that are generated and are known carcinogens. This approach will also entail additional GAC treatment to remove the chlorine and result in additional energy costs to steam and sanitize the carbon tower. Carbon towers are a known source of microbial contamination as they serve as incubators for gram-positive and gram-negative bacteria.

Remediation:_ HOD UV for recirculation and production water treatment with recirculation on on a slipstream basis. As stated above, Atlantium will TRIPLE the 40 mJ/cm^2 dose requirement for recirculation of stored water to enable 4-5 log reduction of viruses, bacteria and other organisms.

Risk: Air Stripper Treatment with Chlorine requires a high amount of chlorine feed due to the surface contact with air as well as the chlorine oxidizing the VOC's. Chlorine addition can make VOC compounds more refractory. Plus, chlorine resistant organisms can make biofilm on the stripper, reducing the efficiency of the stripper.

Remediation: HOD UV Treatment that offers superior disinfection on chlorine resistant organisms, will prevent fouling, and offers some oxidation potential on chlorinated organics.

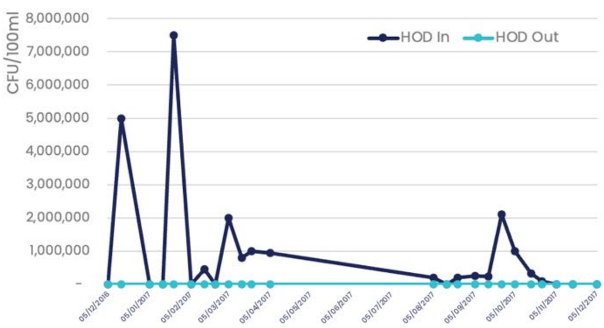
NOTE:
If the end user will supply Atlantium with a list of organisms that are speciated, Atlantium can put together a table for each application, showing the log reductions that will be obtained for each organism at a specified flow rate and UV transmittance value. common organisms seen are pseudomonads, e.coli, norovirus, among others.

All Exceed the highlighted requirements, and can render a 4 log reduction (99.99%) of Adenovirus Without the use of any additional technology
The use of Chlorine in the water system can be greatly curtailed or even eliminated based on proper placement of high dosage Atlantium HOD UV systems.
The following slides show real time data examples from Beverage facilities around the world and indicate successful water system operation with no chlorine while being FULLY COMPLIANT by a Major Beverage Company Standards. There are host of ancillary benefits as shown in the slides.

Moving Towards Green Production Process

Challenge

Reduce environmental footprint & improve water to product ratio



Outcome

Preservative-free production improved product to water ratio to 1.63 liters of water per 1 liter of product

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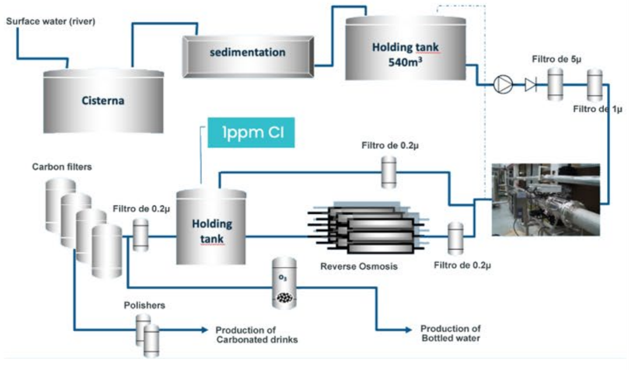
Chlorine Free Production I

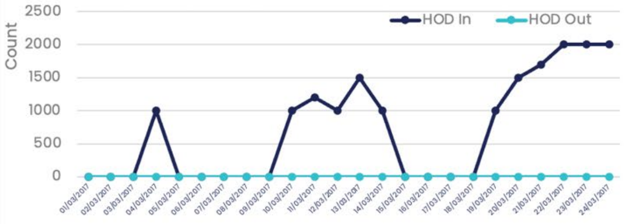
Challenge

High organic matter concentration
in water source produces THMs when chlorine is used



Outcome

HOD as primary disinfection barrier provides complete microbiological inactivation and improves performance of downstream cartages and RO membranes



Significant Cost Savings

Parameter	RO membrane		Absolute filter	
	Before ATL installation	**After ATL installation**	**Before ATL installation**	**After ATL installation**
CIP frequency	**Once a quarter**	**Aug 08 till March 09** - NO CIP was performed	Weekly or according to Differential pressure	
Cartage changing frequency	–	–	**Once a month** (25 or 30 days)	**Once a quarter** (75 or 90 days)
CIP method	Circulation with Acid and Alkaline solutions		CIP with Chlorine and Sulfuric Acid for pH control	
CIP cost	**Weekdays**: $7,590 (90,000 Pesos) **Weekends:** $12,650 (150,000 Pesos)		–	–
Savings & Remarks	CIP is outsourced and usually performed on weekends	**Assumed savings 2 quarters:** $15,200-25,300 (180,000-300,000 Pesos) No pressure drop	**22 cartages in a filter** 2 X 40" filter each cartage $200 1 X 30" filter Each cartage $130.	**Assumed savings 2 quarters:** $46,640

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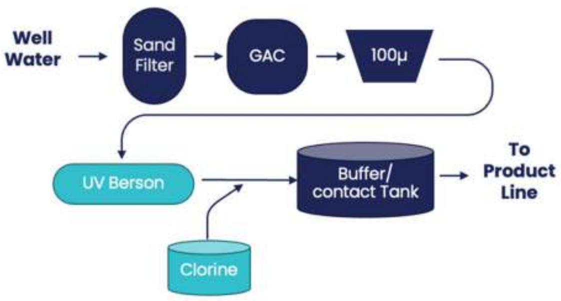
Chlorine Free Production II

Challenge

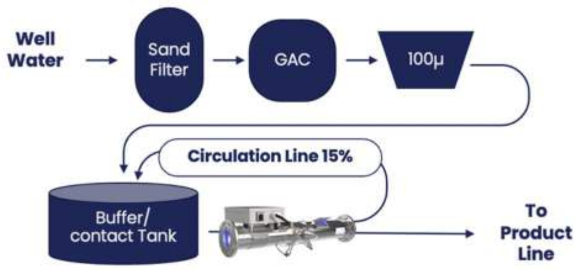
Continuous contamination by
Pseudomonas and Coliforms in the product water



Outcome

5 log inactivation guarantee
for both Pseudomonas and Coliforms
Chlorine free production

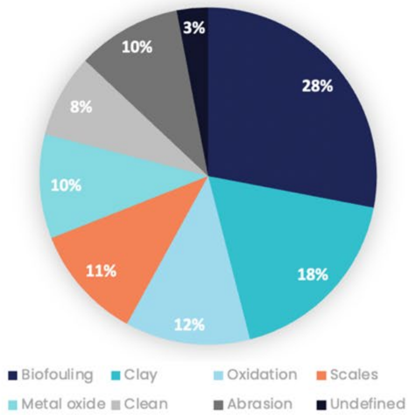
After HOD



Protect your RO Membranes

Challenge

Biofouling is related to ~80% of membrane failures



Outcome

Prolong membrane lifespan
Prevent contamination and microbiological growth

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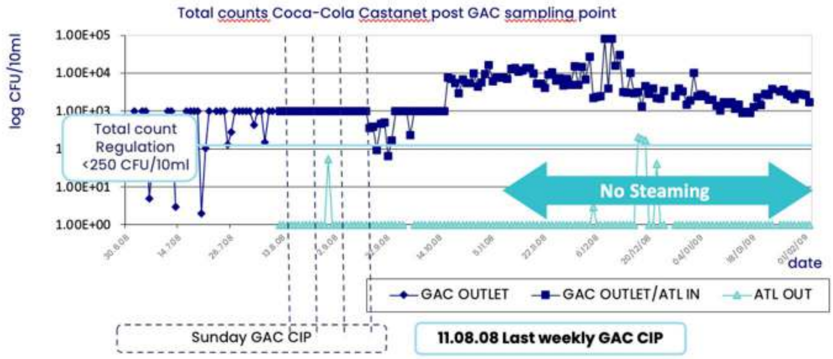
Reduce CIP Intervals, Eliminate Unscheduled CIP

Challenge

Chronic contamination in production lines downstream to GAC filter required frequent CIP, both scheduled and unscheduled

Outcome

Meeting Coca Cola's microbial standards CIP schedule changed from 1 per week to 2 per year Sampling at far sample points (blender & syrup room) significantly improved Plant savings >100,000€ / year



Maintain Microbial Standard at Far Sampling Points

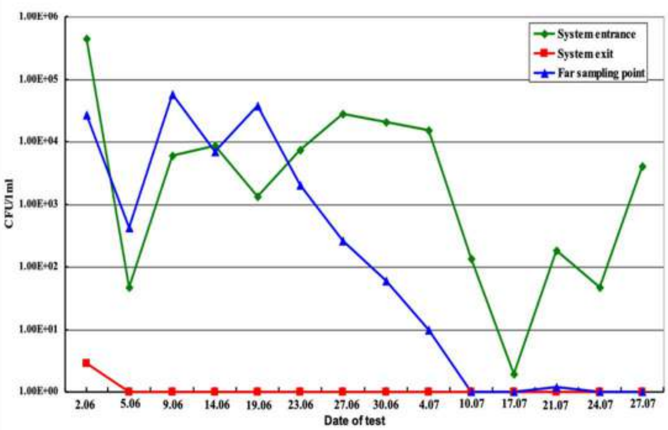
Challenge

Reduce chlorine dosing at intake and maintain microbiological standard

Outcome

Changed chlorine injection point to pipe instead of to the reservoir

Consistently high-quality water had immensely positive effect on far-sampling points



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