Optimizing Four-Log Virus Treatment with Chemical Disinfection Relative to the Disinfectants and Disinfection Byproducts Rule

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Regulatory Review

Stage 2 Disinfectants and Disinfection Byproducts Rule

The Stage 2 Disinfectants and Disinfection Byproducts Rule (D/DBPR) is aimed at reducing potential cancer and reproductive and developmental health risks from disinfection byproducts (DBPs) that are formed when disinfectants (e.g., chlorine) combine with naturally occurring dissolved organics (DBP precursors) during the disinfection process. The Stage 2 rule tightens compliance monitoring requirements in the Stage 1 rule for two groups of DBPs: total trihalomethanes (TTHMs) and five haloacetic acids (HAA5). Under the Stage 2 D/DBPR, utilities are required to conduct an Initial Distribution System Evaluation (IDSE) to identify locations with high DBP concentrations, which are then used as monitoring locations. Compliance is determined by calculating locational running annual average levels at the selected monitoring locations throughout a distribution system.[1] The maximum contaminant levels (MCLs) for the regulated DBPs were not changed from the Stage 1 rule under the Stage 2 rule, and remain as follows:

- TTHMs: 80 µg/L
- HAA5: 60 µg/L.

The primary reason that the Stage 2 rule incorporates locational sampling within the distribution system is that the DBP formation reactions can continue as the treated finished water is pumped from the treatment plant and flows to the customer through the distribution system, resulting in varying levels of DBPs. This is particularly true in distribution systems that carry a free chlorine residual. For this reason, most utilities in Florida that have significant levels of DBP precursors in their raw water supplies utilize chloramines as a secondary residual disinfectant in the distribution system. Chloramines do not react significantly with DBP precursors to form DBPs, and the addition of ammonia in the presence of free chlorine and DBP precursors effectively quenches the DBP formation reactions.

Although these formation reactions can continue in the distribution system, the two most common strategies employed by utilities in Florida for controlling DBPs and complying with the subject requirements are employed at the treatment plant in the treatment process. The first is aimed at reducing the levels of DBP precursors in the treated water to the greatest degree possible prior to the addition of chlorine. Strategies for reducing DBP precursor levels involve treatment process modifications aimed at improving the removal efficiency for dissolved organic materials, such as incorporating enhanced lime softening, the addition of an anion exchange treatment step for organics removal, and/or the addition of a nanofiltration or membrane softening process to the overall treatment process.

The second strategy is to control the disinfection process so as to minimize the opportunity for DBP formation during primary disinfection. In general, this strategy focuses on the factors that influence the rate and degree of completion of the DBP formation reactions. These factors include the concentrations of both the DBP precursors and disinfectant (chlorine) in the process stream, the time available for the reactions to occur, the water temperature, and pH. For example, reducing the free chlorine concentration in the primary disinfection zone will reduce the levels of DBPs that are produced. Similarly, reducing the amount of time that the free chlorine concentration is in contact with the treated water will reduce the levels of DBPs that are produced in the finished water. Of course, there is a limit to how far these parameters may be reduced and still provide satisfactory disinfection. Consequently, there is a trade-off between minimizing DBP formation and providing effective disinfection.

Due to the superior effectiveness of free chlorine as a disinfectant, many utilities use free chlorination during the primary disinfection process, and then add ammonia following primary disinfection to quench the DBP formation reactions and form a combined chloramines secondary residual disinfectant. As discussed further, under current applicable

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regulations, the criteria for achieving and demonstrating satisfactory primary disinfection of the treated water include the concentration of disinfectant maintained in the process stream and the amount of time the disinfectant remains in contact with the treated process stream, as well as the water temperature and pH of the treated water. These parameters have the most influence on the formation of DBPs during primary disinfection. Systems that utilize free chlorination for primary disinfection, followed by the addition of ammonia to form a combined chloramines residual disinfectant, are presented.

Surface Water Treatment Rule and Ground Water Rule

On June 29, 1989, the U.S. Environmental Protection Agency (EPA) enacted the Surface Water Treatment Rule (SWTR), which applies to public water systems that use surface water sources for their raw water supply. On Nov. 8, 2006, EPA published the final Federal Groundwater Rule (GWR) which applies to public water systems that use groundwater sources for their raw water supply. Under these rules and other related state regulations, drinking water utilities are required to provide certain levels of disinfection of treated drinking water, depending on various factors, such as the raw water source (e.g., surface water, groundwater, or groundwater "under the influence" of surface waters), whether the water is exposed to the open atmosphere during treatment, the method of treatment, etc.

Under the GWR and Chapter 62-550.828, Florida Administrative Code (FAC), groundwater systems with their own groundwater

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sources shall provide four-log virus treatment for those sources, or conduct "triggered" and "assessment" microbial monitoring of their groundwater sources. Chapter 62-550.828, FAC, also requires groundwater systems exposing their water to the open atmosphere during treatment to provide four-log virus treatment of their groundwater after it is last exposed to the open atmosphere, or conduct assessment microbial monitoring of their finished water before or at the first customer.[2] The preferred strategy for complying with these requirements for many utilities is to provide four-log treatment with their physical treatment processes (e.g., conventional filters or membrane process) and/or through chemical disinfection.

The Florida Department of Environmental Protection (FDEP) has published *Guidelines for Four-Log Treatment of Groundwater* (October 2009) to provide Florida utilities some guidance in complying with the GWR in accordance with state policies. The level of inactivation or removal of any microorganism, including viruses, generally is measured on a logarithmic scale (i.e., in terms of orders of magnitude). For example, four-log virus treatment means inactivation or removal of 99.99 percent of viruses in the treated water.[3] The *Guidelines* lists various treatment technologies, including chemical disinfection, as accepted technologies for virus treatment. The *Guidelines* also lists "virus treatment credits" for various disinfection and treatment technologies[4].

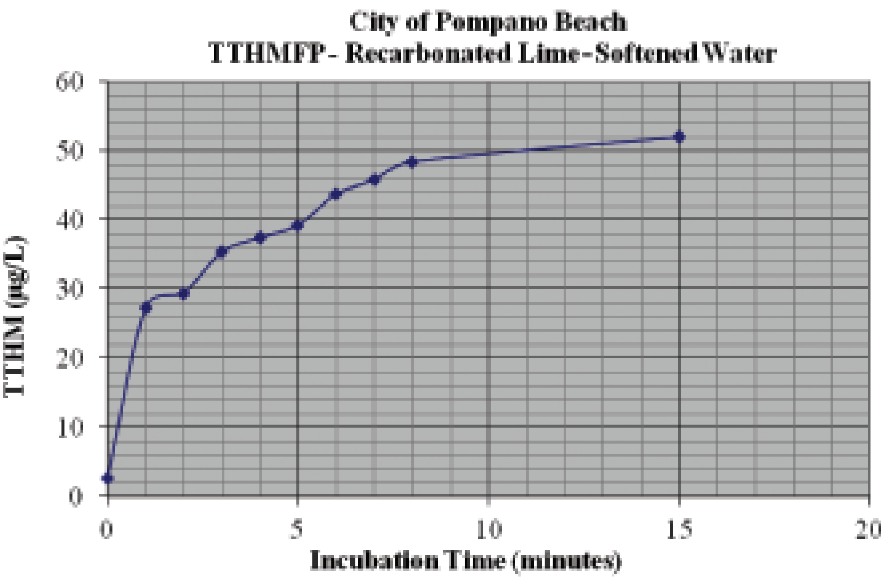

Figure 1. City of Pompano Beach Lime-Softened Water TTHMFP Curve

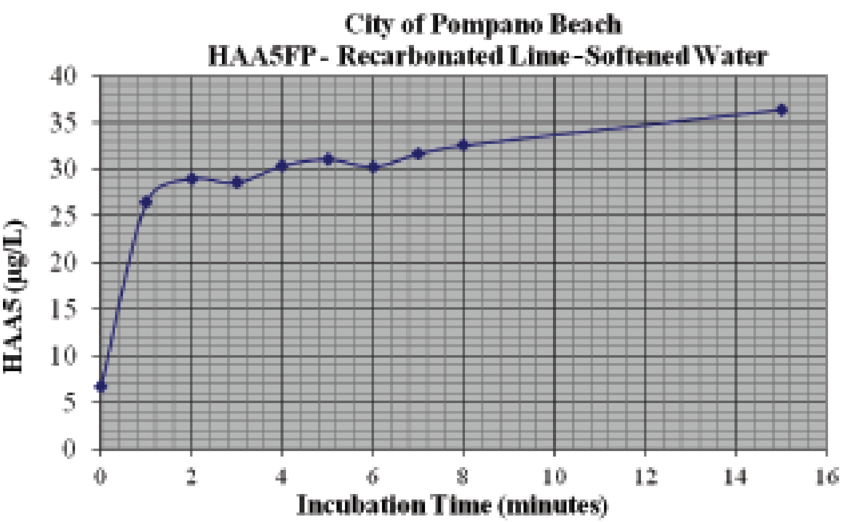

Figure 2. City of Pompano Beach Lime-Softened Water HAA5FP Curve

For chemical disinfection (e.g., disinfection with chlorine), the virus removal credits are based on a calculated CT value for the selected disinfectant and prevailing conditions in the treatment process, relative to the applicable CT table included in the *Guidelines*, which are based on tables published by the EPA. The CT is the product obtained by multiplying the residual disinfectant concentration (C), in milligrams per liter (mg/L), measured before or at the first customer, times the corresponding disinfectant contact time (T), in minutes.[5] According to the SWTR, the contact time (T) for a vessel is the time at which 10 percent of the amount of water entering the inlet has passed through to the outlet. This theoretical time is called T_{10}, and is estimated as the product of the hydraulic detention time (HDT) in a vessel (calculated as the volume divided by the flow) times a baffling factor, which is based on the flow characteristics of the particular vessel used for disinfectant contact.[6]

One popular strategy for providing four-log virus treatment to comply with the GWR utilizes chemical disinfection with free chlorine. For many utilities, this is the simplest, most reliable, and most easily implementable option available to comply with these requirements. However, this strategy presents the potential for increased formation of undesirable DBPs, such as TTHM and HAA5. This issue is of particular concern for utilities in Southeast Florida that utilize the Biscayne Aquifer, which is high in color and dissolved organics, as a raw water source.

The compliance date in Florida for the four-log virus removal/inactivation requirements under the GWR, which applies to most Florida utilities, was Dec. 1, 2009. Under the GWR, the state shall determine a residual disinfection concentration necessary to provide the target log treatment for that system, and the groundwater system must maintain this residual in the "disinfection zone" to demonstrate compliance.

The simplest interpretation of the language in the GWR is to determine a fixed disinfectant residual concentration to be used under all conditions for each system. However, it places restrictions on a utility's flexibility to optimize their processes to comply with the D/DBP rule.

Under the current regulatory policy in Florida, if a utility elects to provide four-log virus treatment using chemical disinfection to comply with the GWR, the utility must determine a minimum target disinfectant residual based on the following assumptions:

- Peak (maximum) flow through the disinfectant contact vessel
- Minimum contact vessel volume
- Minimum temperature observed based on historical temperature data

- One pH range based on historical data for the process
- Applicable and approved baffle factor(s) for the disinfectant contact vessel(s)

The target disinfectant residual is then calculated to achieve the appropriate CT value required to provide four-log treatment based on the applicable CT table. The plant is then required to maintain this disinfectant residual level at all times and under all conditions from that point forward to maintain compliance with the rule. The assumption of the worst-case process flow rate, contact vessel volume, and water temperature, all occurring simultaneously, for the purpose of estimating a target disinfectant residual to maintain under all future conditions, presents significant challenges to utilities using free chlorine disinfection in complying with the D/DBPR. Because increases in free chlorine concentration (C) and residence time (T) both have positive impacts on the rates of the DBP formation reactions, maintaining a target free chlorine residual level substantially greater than that necessary to achieve four-log disinfection under the prevailing conditions may result in a direct and unnecessary increase in the formation of DBPs during the primary disinfection process.

The objectives of DBP control (under the Stage 2 D/DBPR) and primary disinfection (under the Federal GWR or the SWTR) are in competition with respect to the two most important and controllable of these parameters: chlorine concentration and contact time. This trade-off is, of course, recognized by the regulatory agencies, and it fact there are references to it in the *Guidelines*.[7] At present, the FDEP's policy regarding the application of chemical disinfection to achieve four-log treatment under the GWR is still in draft form. Due to the fact that the GWR mandates that states determine a minimum target residual, under current policy there is little flexibility for utilities to optimize their disinfection processes with respect to both rules. However, it is worth recognizing that it is at least technically feasible to reliably meet the treatment objectives of both rules, and to optimize the disinfection process with them in mind. To that end, there are some optimization opportunities discussed that are not feasible under current regulatory policy, but are presented for informational purposes.

Optimization Parameters

The specific scenario presented here is of a utility that uses free chlorination of a treated process stream that has significant levels of DBP precursors to provide four-log disinfection, followed by the addition of ammonia, after meeting the applicable disinfection criteria to halt the formation of DBPs and form a chloramine residual.

The critical parameters that provide an opportunity for optimization with respect to the objectives of the two regulatory requirements described include contact time, disinfectant concentration, and temperature. These parameters are discussed in greater detail.

Contact Time

The effect of contact time on the formation of DBPs is typically characterized by developing a formation potential (FP) curve for the DBP of interest, using water samples that are representative of the treated water and a disinfectant dosing rate that is representative of the proposed dosing scheme. To prepare the curve, a series of water samples are dosed with chlorine at time (T) = 0, and the DBP formation reactions are quenched with the addition of ammonia at varying time intervals for each sample. The samples are then analyzed for the DBP of interest, and the results are plotted, with incubation time on the X axis and the

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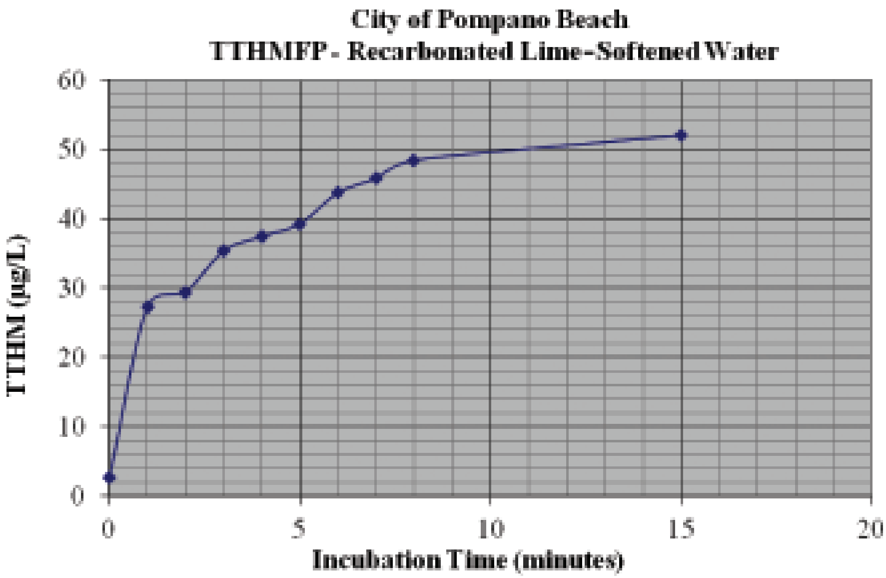

Figure 3. BCWWS WTP 1A Lime-Softened Water TTHMFP Curve

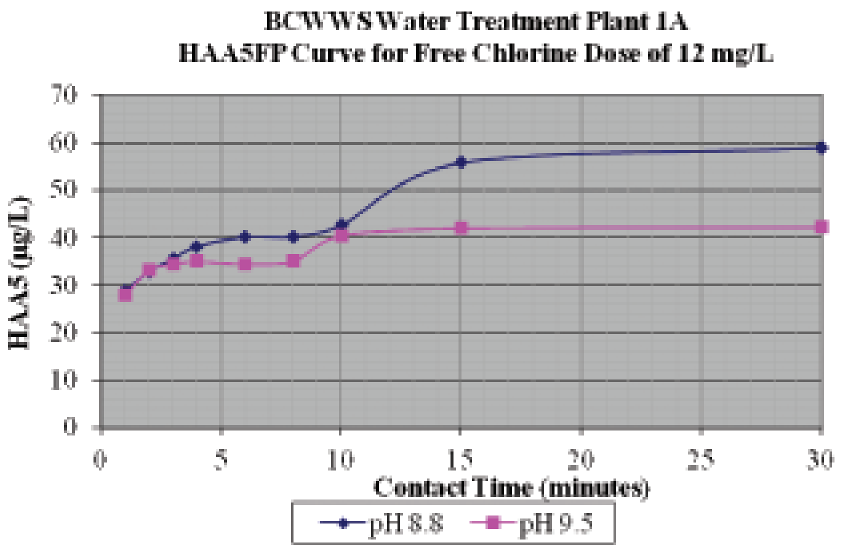

Figure 4. BCWWS WTP 1A Lime-Softened Water HAA5FP Curve

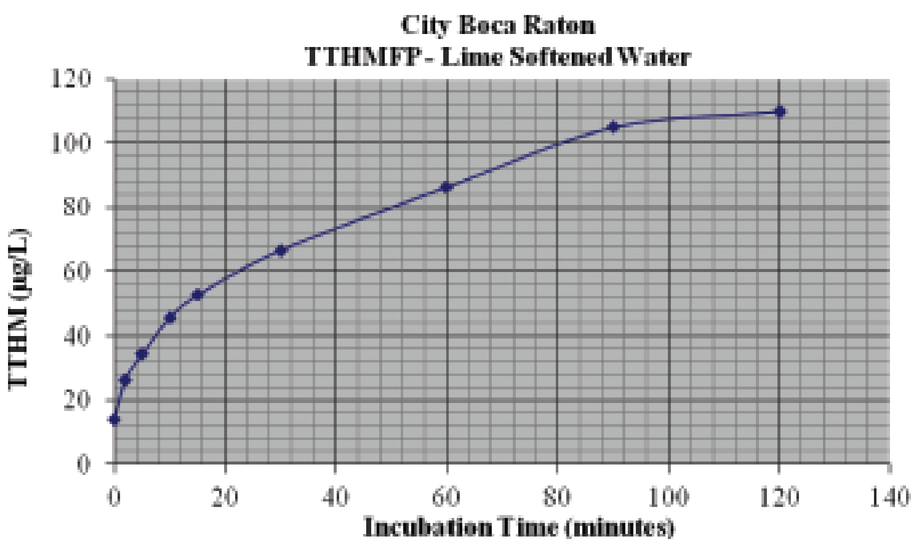

Figure 5. City of Boca Raton Lime-Softened Water TTHMFP Curve

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DBP level on the Y axis. Figures 1 through 6 present TTHM formation potential (TTHMFP) and HAA5FP curves for process water samples that were evaluated at three different water treatment plants for the City of Boca Raton, the City of Pompano Beach, and the Broward County Water and Wastewater Services Water Treatment Plant 1A, respectively.

It should be noted that the Boca Raton and Pompano Beach water treatment plants incorporate membrane softening processes in combination with conventional lime softening processes, with the product waters blended to produce the finished water supply. Therefore, the strategies for controlling the levels of DBPs in the finished water include greatly reducing DBP precursor levels in a significant portion of the total plant flow through the use of membrane treatment, as well as minimizing the formation of DBPs during primary disinfection by managing the chlorine dosing rate and contact time. The Broward County plant does not have a membrane process, so its strategy focuses on minimizing the formation of DBPs during primary disinfection.

The DBPFP curves presented are based on analytical data from the facility referenced, but in some cases, may not be indicative of the finished water produced by the plant. For example, the DBPFP curves for all three facilities are for the lime-softened stream only (the DBP formation potential for the membrane permeate is negligible), whereas the finished water is a blend of membrane permeate and lime-softened water.

The City of Pompano Beach currently blends the membrane permeate with the lime-softened water prior to disinfection. Therefore, the composite DBPFP for the blended stream should be substantially lower than that indicated by Figures 1 and 2. The DBPFP curves presented in Figures 1 and 2 for Pompano Beach were prepared at a time when the City was considering a disinfection scheme that addressed the two streams separately, prior to blending, so these curves were relevant to that scenario. The DBPFP curves for the Pompano Beach lime-softened stream are not representative of current conditions at the plant, but are used to illustrate the potential results of optimization alternatives for a similar facility with a conventional lime softening process only.

The City of Boca Raton currently disinfects the membrane permeate and lime softening process streams separately, prior to blending. Therefore, the DBPFP curves presented in Figures 3 and 4 are representative of current conditions in the lime softening stream, but not in the blended finished water.

With respect to the four-log virus treatment criteria under the GWR, three strategies are discussed for optimizing the process with respect to contact time.

Improving the Baffle Factor

The first strategy is to improve the baffle factor of the disinfectant contact vessel. The relationship between CT and the baffling factor is as follows:

$$CT = (C \times BF \times V) / Q$$

where
C = chlorine residual in mg/L
BF = disinfectant contact vessel baffle factor
V = disinfectant contact vessel volume in gallons (gal)
Q = process flow rate in gallons per minute (gpm)

Assuming that a utility is working with a specific structure as the disinfection contact vessel in which the CT necessary to achieve the desired level of virus treatment will be provided, improving the baffle factor by adding internal baffling will allow the utility to either reduce the required chlorine residual at a given contact volume and process flow rate, or reduce the required contact volume (and thus the contact time) at a given chlorine residual and process flow rate.

As an example, consider the City of Pompano Beach clearwell depicted in Figure 7. The original structure was a rectangular vessel (161 ft long x 98 ft wide x 5 ft deep) with no internal baffling. The Pompano Beach water treatment plant is a 50-million-gallon-per-day (mgd) facility with a 40 mgd lime softening

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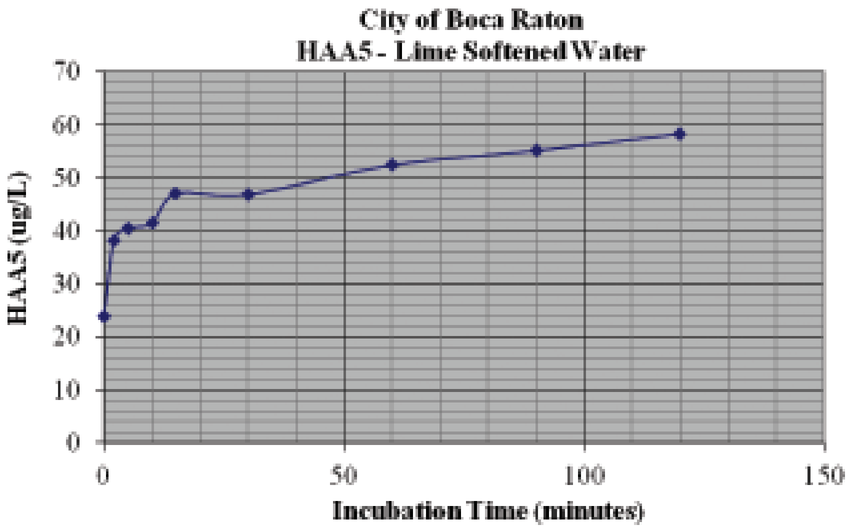

Figure 6 – City of Boca Raton Lime-Softened Water HAA5FP Curve

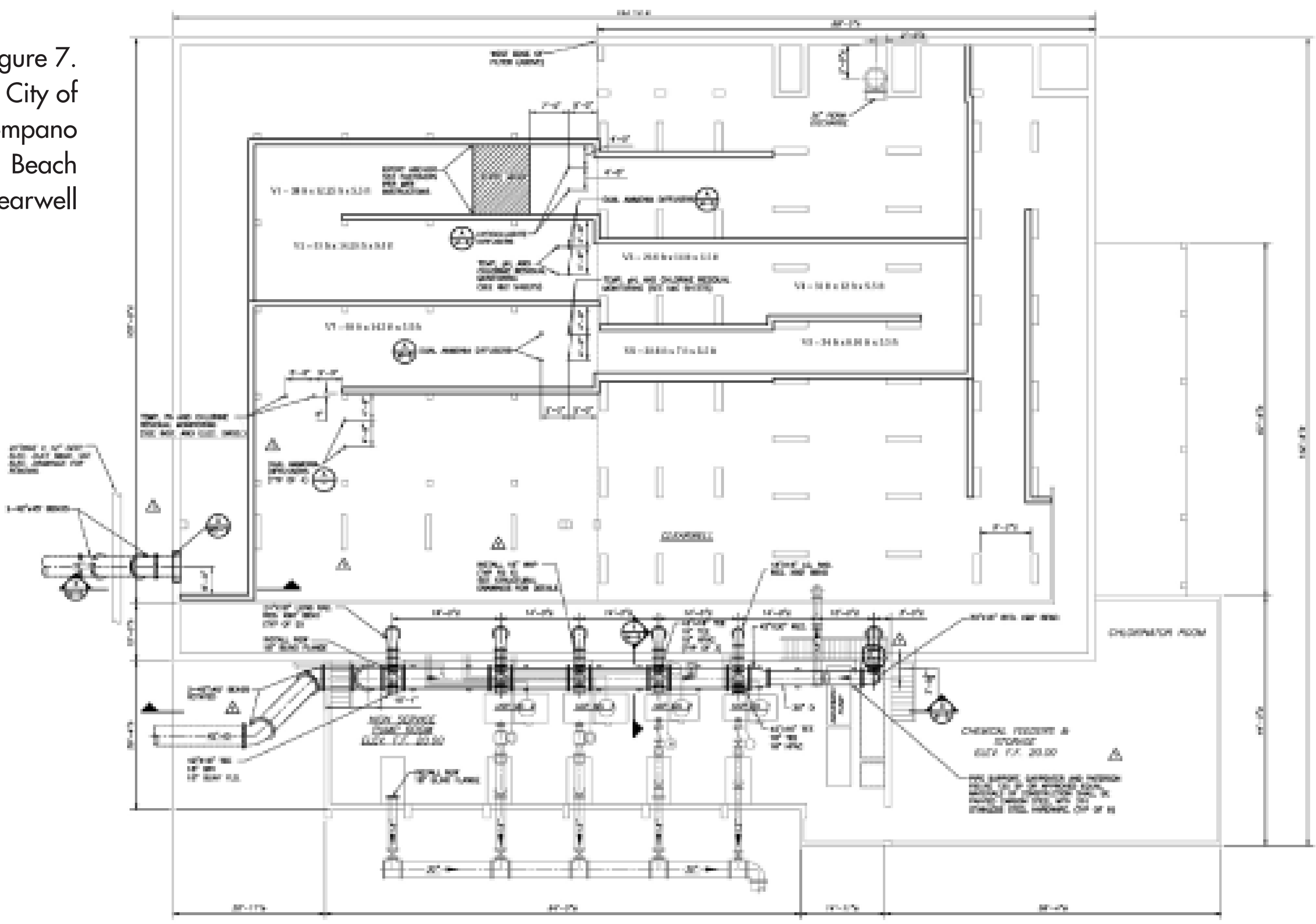

Figure 7. City of Pompano Beach Clearwell

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process and a 10 mgd nanofiltration process, with the membrane permeate and lime-softened water blended in the subject clearwell. If the original unbaffled clearwell had a baffle factor of 0.1, the chlorine residual necessary to achieve the City's target CT of 3 mg-min/L (assuming a water temperature of 20OC and a pH between 6 and 9 as necessary to provide four-log virus treatment within this vessel) would be

$$\begin{aligned} C &= (CT \times Q) / (BF \times V) \\ &= [(3 \text{ mg-min/L}) \times (34{,}772 \text{ gpm})] / (0.1 \times 590{,}100 \text{ gal}) \\ &= 1.8 \text{ mg/L} \end{aligned}$$

The hydraulic detention time (HDT) in the clearwell under these conditions would be

$$\begin{aligned} HDT &= V/Q \\ &= (590{,}100 \text{ gal}) / (34{,}772 \text{ gpm}) \\ &= 17 \text{ minutes} \end{aligned}$$

For the sake of illustration only, if the DBP formation potential curves depicted in Figures 1 and 2 for Pompano Beach were representative of the process water (which they are not, due to the fact that the actual process stream contains a significant portion of NF permeate with negligible levels of DBP precursors), this scenario might result in TTHM and HAA levels of approximately 52 and 36 µg/L, respectively.

By comparison, Figure 7 depicts baffle walls that were constructed within the clearwell to provide more plug-flow characteristics in a serpentine flow pattern. This has two distinct benefits. First, simply improving the baffle factor from 0.1 to 0.5 reduces the required chlorine residual level from 1.8 mg/L to 0.35 mg/L under the same conditions described above. The HDT remains the same at 17 minutes.

The second substantial benefit is that the serpentine flow path provides the opportunity to strategically locate the chlorine application point immediately after blending, and an ammonia application point shortly after the required contact time is provided under the given conditions and at a selected target chorine residual level. For example, at a target chlorine residual of 1.5 mg/L, the required contact volume necessary to provide four-log treatment is

$$\begin{aligned} V &= (CT \times Q) / (BF \times C) \\ &= [(3 \text{ mg-min/L}) \times (34{,}772 \text{ gpm}] / [(0.5) \times (1.5 \text{ mg/L})] \\ &= 139{,}100 \text{ gallons} \end{aligned}$$

The hypochlorite solution and ammonia application points depicted in Figure 7 were located to provide this contact volume; the HDT within this volume, during which DBPs might be formed, is four minutes. Again, for the purpose of comparison to the unbaffled condition only, this scenario might result in TTHM and HAA5 levels of approximately 37 and 30 µg/L, respectively for a pure lime-softened stream, a reduction of approximately 30 percent and 17 percent, for TTHM and HAA5, respectively.

Matching the Ammonia Application Point to Plant Flow Conditions

The second strategy related to contact time for optimizing the process is made possible by the construction of baffle walls to provide a more plug-flow, serpentine flow pattern. This allows the installation of ammonia application points at varying lengths along the process stream flow path so that the plant operations staff can select the ammonia application point based on the actual process flow rate, rather than locating the ammonia application point based on the plant capacity flow rate under all conditions. It should be noted that this strategy is not a viable option under current regulatory policy.

As an example, consider the Broward County plant, a conventional lime softening plant with a 16 mgd capacity. Current average daily demands (ADD) at the plant are approximately 8 mgd. The County's strategy for providing four-log treatment is to achieve a two-log removal credit with the existing dual-media gravity filters, and to provide at least two-log virus disinfection with free chlorination in the East Clearwell. Figure 8 depicts a mechanical plan of the East Clearwell, where baffle walls were constructed to provide semi-plug-flow conditions in a serpentine flow path. The modifications to this clearwell were designed in 2008 based on the four-log treatment requirements under Chapter 62-555.320(12), FAC (the "bird rule"), before the FDEP published the *Guidelines* for the GWR. The designed modifications do provide compliance with the disinfection criteria under the GWR, but also include features that presumably would have been allowed under the bird rule, but are not useable under the current regulatory policy with respect to the similar requirements under the GWR, as described below.

Sodium hypochlorite solution is applied immediately upstream of a static mixer installed in the flow channel (the hatched area in the figure). Ammonia application points were provided at two separate locations within the channel. The last ammonia application point was located to provide a free chlorine contact volume of approximately 37,400 gallons (based on a worst-case scenario of a CT value of 4 mg-min/L using a chlorine residual of 2.5 mg/L, at a process flow rate of 16 mgd, and an assumed water temperature of 15OC) as necessary to provide four-log treatment. An intermediate ammonia application point was located to provide approximately 18,700 gallons of free chlorine contact volume. This intermediate application point was designed to provide the County with the flexibility to meet different log-treatment goals (i.e., two-log or four-log) depending on whether they were relying on the conventional filtration credit of two-log removal, or on chemical disinfection only, under varying flow conditions. The disinfection schemes made possible by this arrangement are summarized in Table 1. As can be seen in Table 1, and Figures 3 and 4, this system could allow the County to achieve reductions of up to 50 percent and 20 percent of TTHM and HAA5 levels, respectively, relative to the worst-case scenario with respect to DBP formation (i.e., a plant flow less than 8 mgd using the last ammonia application point).

Table 1. BCWWS WTP 1A Disinfection Scenarios Using Multiple Ammonia Application Points

							Projected DBPs	
NH_3 Point	Contact Volume (gal)	Flow (mgd)	Chlorine Residual (mg/L)	CT Provided (mg-min/L)	Treatment Achieved	HDT (min)	TTHM (µg/L)	HAA5 (µg/L)
Intermediate	18,700	8	2.50	4.2	4-log	3.4	31	34
Intermediate	18,700	8	1.25	2.1	2-log	3.4	31	34
Intermediate	18,700	16	2.50	2.1	2-log	1.7	22	32
Last	37,400	8	0.63	2.1	2-log	6.7	44	40
Last	37,400	8	1.25	4.2	4-log	6.7	44	40
Last	37,400	16	1.25	2.1	2-log	3.4	31	34
Last	37,400	16	2.50	4.2	4-log	3.4	31	34

Pacing the Target Chlorine Residual to Actual Flow Conditions

Another possible strategy related to contact time for optimizing the process is to calculate a variable target chlorine residual (and thus a chlorine dosing rate) based on the actual flow conditions, rather than assuming the peak flow to calculate a fixed residual target. For most facilities, the assumption of peak flow results in a target residual that is excessive under most conditions. Most plants operate at a fraction of their design and permitted capacities (i.e., they have built-in, permitted excess treatment capacity) so they never operate under maximum (permitted) flow conditions through the disinfectant contact vessels. Also, because water treatment plants are designed to meet maximum day demands (i.e., the greatest day demand in the build-out design year), even if a plant is operating at capacity, the flow rates through the process will be less than the maximum the vast majority of the time.

The target disinfectant residual to provide a given CT can be calculated as follows:

$$\text{Target Residual} = (CT \times Q) / (BF \times V)$$

If the CT value, baffle factor (BF), and disinfectant contact volume (V) were fixed, a process flow signal could be used to calculate an on-line, real-time target residual based on actual flow conditions. By adjusting this value to compensate for any chlorine demand in the process flow stream (which is normally fairly constant in groundwater systems with a stable raw water quality) and providing a safety margin, this calculation could be used to generate a pacing signal to automatically pace the disinfectant feeder (for example, a hypochlorite solution metering pump) to the process flow stream. If a treated process stream contained a chlorine demand of 3 mg/L, and the utility wished to provide a 0.5 mg/L safety margin, then the paced dosing rate would be

Disinfectant dosing rate
= Target residual + chlorine demand + safety margin.

This control scheme for the disinfectant feeder is certainly technically feasible, and introduces no new sources of uncertainty or potential for reliability issues to systems that have been proven and are already currently in widespread use. Most water treatment plants use a signal from one or more plant flow meters to calculate a disinfectant feed rate (e.g., gallons per hour) based on a constant target dosing rate (mg/L) to pace a feeder (e.g., a gas chlorinator or metering pump). Modifying this common control scheme to calculate a varying target residual involves no additional instruments or signals, simply a change to the control algorithm. This control algorithm could also include a lower limit dosing rate if desired by the utility. For example, the system could be programmed to never dose at less than a 0.5 mg/L dosing rate, even though the calculated target residual may be less than that.

Verification of compliance with the four-log treatment requirements would also be no more complicated than with current systems. Utilities are already required to collect and document the chlorine residual levels at the end of the disinfection zone to compare with the state-mandated targets. These data can be used, with the on-line flow data, to calculate a running CT trend to demonstrate that the target treatment is provided on a continuous basis.

Neglecting the safety margin, this control scheme would result in a reduction in the free chlorine residual target that is proportional to the reduction in the actual process flow rate versus the assumed peak flow rate. The effect

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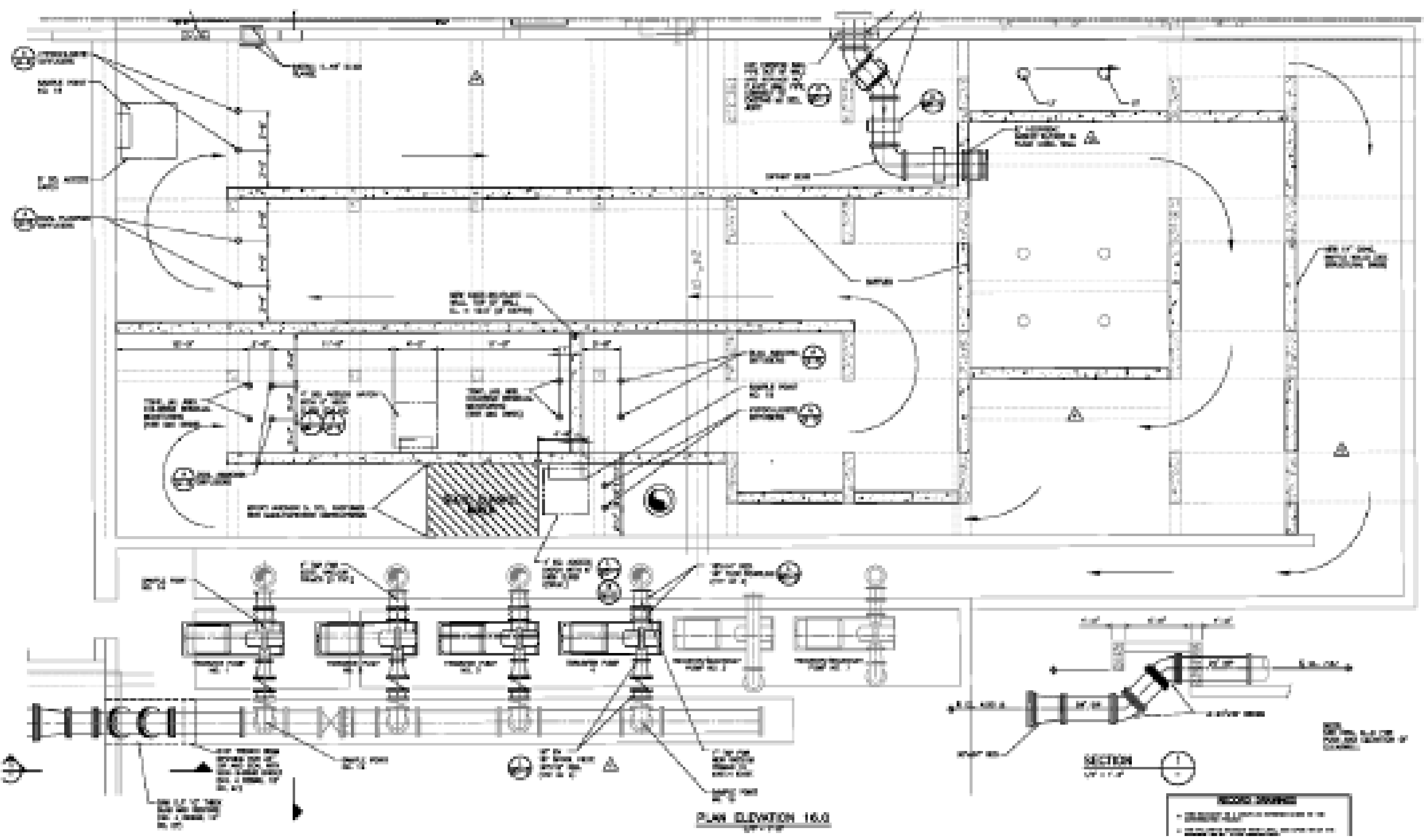

Figure 8. BCWWS WTP 1A East Clearwell

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of a reduction in the free chlorine levels within the disinfectant contact zone on the rate of DBP formation and on the levels of DBPs in the finished water cannot be evaluated with the DBPFP curves that were available for the subject facilities. The relationship between the initial chlorine dose and the shape of the DBPFP curve is highly variable and dependent on the characteristics of the raw water. However, the literature indicates that there is a clear relationship, with higher chlorine residual levels corresponding to steeper DBPFP curves (i.e., faster DBP formation reaction kinetics).

Temperature

The *Guidelines* require that, in the absence of sufficient system-specific water temperature data, systems shall use the minimum water temperature provided in Table D-1 of the *Guidelines* in the determination of the target CT to provide the desired level of virus treatment. The temperature listed in Table D-1 for utilities within the South Florida Water Management District is 18.5°C. Similarly to the process flow rate parameter, water temperature must be continuously monitored to verify compliance. There is no significant technical impediment to utilizing this data, which is already being monitored in real time in the process, to determine the CT requirement applicable for the actual water temperature, rather than making an assumption. This could be accomplished in real time, on a continuous basis, with a lookup function within the plant process control system. Similar to the discussion above relative to process flow, the determination of the applicable CT requirement based on water temperature could then be used in calculating the dosing rate for the chemical feeder.

Consider an example of a system where the water temperature fluctuates during the year from a minimum of 18OC to a maximum of 25°C. Based on Table B-1 from the *Guidelines*, for four-log disinfection with free chlorine at a pH of between 6.0 and 9.0, the applicable CT requirement ranges from 3.4 mg-min/L (at 18°C) to 2 mg-min/L (at 25°C). Under the same flow conditions, this translates to an overdosing of chlorine at the higher temperature condition of 1.4 mg/L. Considering that the rates of the DBP formation reactions increase with increasing temperature and chlorine concentration, the use of the actual water temperature in calculating the dosing rate for four-log treatment could result in a significant reduction in the levels of DBPs in the finished water under certain conditions.

Contact Volume

The contact time (T) in the CT calculation is calculated based on the peak process flow, the contact volume (V), and the baffle factor (BF) of the contact vessel. For closed vessels that remain full at all times (e.g., pipelines), V is constant. For some vessels, such as clearwells and water storage tanks, the water level in the vessel can fluctuate, and the contact volume fluctuates with the water level. The *Guidelines* require that, in these cases, "the volume of water in the tank [used in the CT calculation] shall be determined using the lowest water level expected in the tank during any peak flow period or, to be more conservative, using the minimum possible water level that occur in the tank," (i.e., the pump shutoff level).[8]

Assuming the all-off pump control elevation in the calculation of the contact volume is the most conservative assumption. However, in clearwells where transfer pumps are controlled based on water level, the water levels at various plant flow rates are known and predictable. For example, a very common control scheme for constant-speed transfer pumping systems is to stage the system so that the water level fluctuates between individual pump on/off control elevations in increasing level intervals corresponding to increasing process flow rates. Figure 9 depicts a simplified representation of this control scheme; at low flows, the water levels will fluctuate around the lower control levels, and at the higher flows, the water level will fluctuate between the higher control levels. The minimum water levels under each flow condition is known and predictable, and therefore can be used to calculate the actual CT provided based on the minimum level appropriate for that flow range. For example, in the system illustrated in Figure 9, when the process flow is between 0 and 1 mgd, the water level in the clearwell will fluctuate between 6 ft and 8 ft NGVD (National Geodetic Vertical Datum), with the minimum water level being 6 ft NGVD. However, when the process flow is between 3 and 4 mgd, the water level will fluctuate between 12 ft and 15 ft NGVD, never falling below 12 ft NGVD until the flow rate falls outside of this range. This is potentially of significant benefit, because the peak flow conditions typically correspond to worst-case CT conditions, under which a greater disinfectant contact volume is required to meet a given CT target.

Alternatively, for systems where the rate of change in the water level in the disinfection contact vessel is not significant relative to the residence time in the vessel, the actual level, as measured by a level sensor, could be used to calculate the contact volume and contact time for that time interval. This would not be appropriate if the rate of change in the water level was significant in relation to the T_{10} value (i.e., if the actual contact volume changed significantly within one T_{10} time interval).

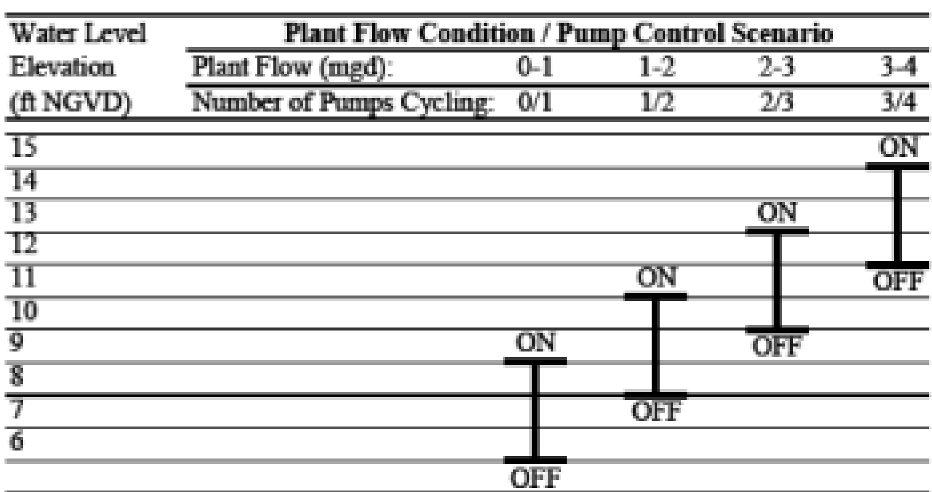

Figure 9 – Schematic of Typical Constant-Speed Transfer Pump Control Scheme

Potential for Automated Four-Log Treatment Control and On-Line Compliance Documentation

All of the parameters that are necessary to calculate the chlorine residual level to provide four-log treatment under the prevailing conditions in a treatment process must be monitored under current regulations in order to verify compliance (i.e., process flow, temperature, pH, temperature, and chlorine residual). Given this fact, it is technically feasible to design a system that will allow for on-line, real-time monitoring of the parameters that are used to calculate a CT value, thereby establishing a certain level of virus treatment, and using the data from those monitored parameters to perform the following:

1. To generate a control signal to automatically control the disinfectant dosing rate to the disinfection process, as necessary to provide the CT to achieve the desired level of treatment under the conditions observed and recorded at that time.
2. To continuously calculate, record, and document the minimum CT value and/or level of virus treatment achieved by the treatment process.

Figure 10 depicts a simple schematic of an example of the use of such a system, where the system is programmed with the following characteristics:

Target treatment	*Four-log treatment*
Disinfectant	*Free chlorine residual using a 12 percent sodium hypochlorite solution*
Disinfectant Feeder	*Pacable positive displacement metering pump with a linear flow profile from 0 to 1.0 gallons per hour (gph), receiving a 4-20 mA control signal, i.e., if the pump receives a 4 mA signal, the pump output will be 0 gph, if the pump receives a 20 mA signal, the pump output will be 1.0 gph, and within those boundaries, the pump output will be proportional to the signal.*
Disinfectant contact vessel	*Rectangular 10 ft x 10 ft basin with a baffle factor of 0.3*

Disinfectant Feeder Pacing

In this example, the disinfectant feeder pacing program would first observe the pH and temperature values from the system devices. From the pH reading, the program would select Table B-1 from the *Guidelines* and then, from the temperature reading, determine the target CT to achieve the target treatment of four-log inactivation to be 4 mg-min/L. The program would then observe the flow and water level from the system devices. Using these data, the program would calculate the target residual as follows:

Target residual
= (CT x process flow) / (baffle factor x volume)
= [(4 mg-min/L) x (351 gpm)] / [(0.3) x (10 ft x 10 ft x 5 ft) x (7.48 gal/ft^3*)]*
= 1.25 mg/L

If the treated process stream contained a chlorine demand of 1 mg/L, and if it were assumed in this example that the utility wishes to provide a 0.5 mg/L safety margin, then the dosing rate would be:

Disinfectant dosing rate
= target residual + disinfectant demand + safety margin
= 1.25 m/L + 1 mg/L + 0.5 mg/L
= 2.75 mg/L

In summary, under the above conditions, the application of chlorine to the process flow stream at a dosing rate of 2.75 mg/L should neutralize the 1.0 mg/L chlorine demand in

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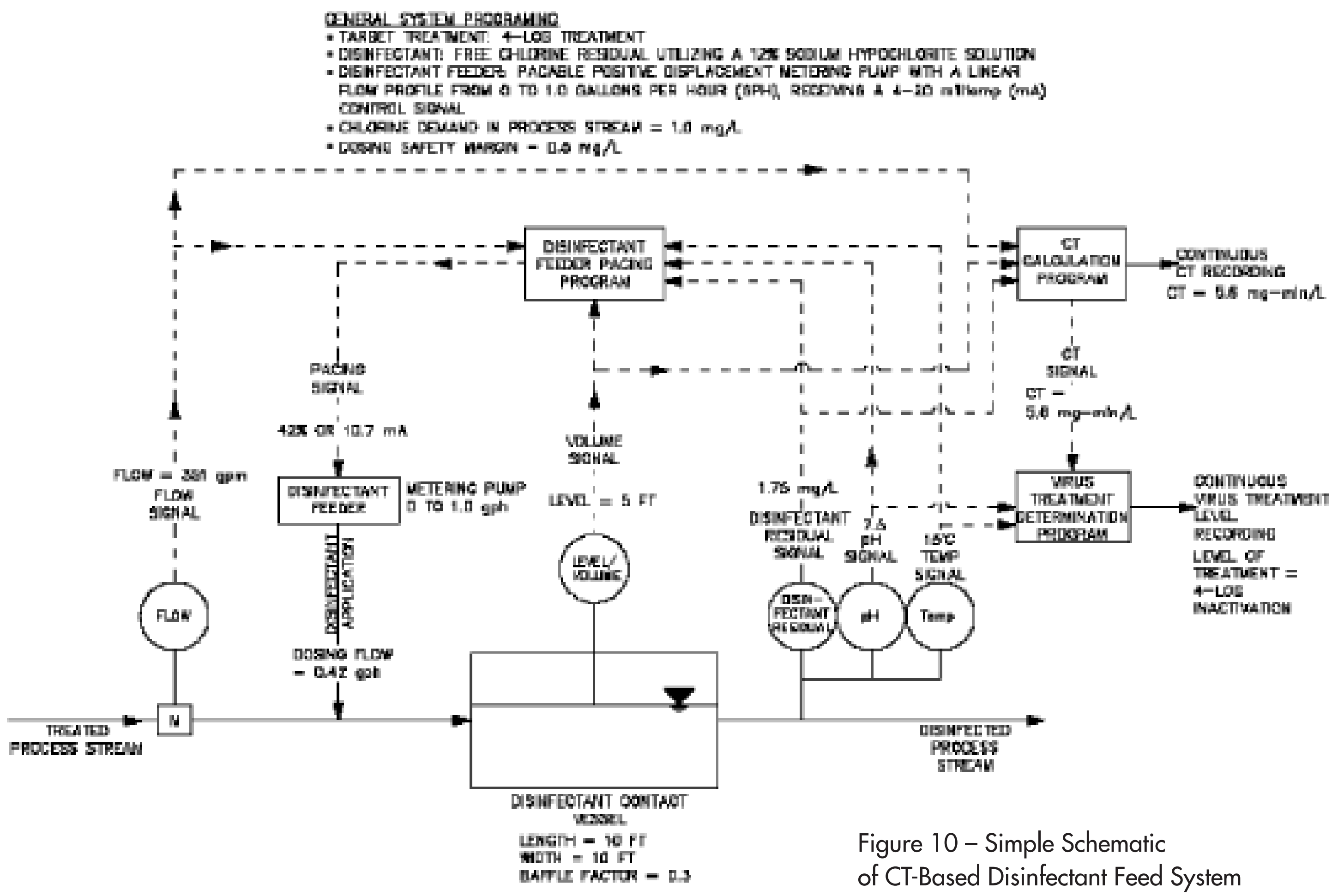

Figure 10 – Simple Schematic of CT-Based Disinfectant Feed System

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the water and result in a chlorine residual of 1.75 mg/L, providing a 0.5 mg/L safety margin over the residual level of 1.25 mg/L required to provide a CT of 4, as necessary to achieve a four-log level of treatment.

CT Calculation and Documentation

The CT calculation program would consider the flow rate, disinfectant contact vessel volume, and baffle factor to calculate a T_{10} value, and then utilize the observed disinfectant residual signal to calculate and record a CT value. As an example, consider the case illustrated in Figure 10; the calculation of CT from the available data would be:

$$CT = [(C) \times (BF) \times (V)] / Q$$

If, at a given point in time, the following conditions are observed by the monitoring devices:

Process stream flow rate =	*351 gpm*
Disinfectant contact vessel Level sensor reading:	*5 feet (depth)*
Chlorine residual reading:	*1.75 mg/L*

The calculated result of the CT Calculation Program would be:

$$CT = \{(1.75\ mg/L) \times (0.3) \times [(10\ ft \times 10\ ft \times 5\ ft) \times 7.48\ gal/ft^3)]\} / (351\ gpm) = 5.6\ mg\text{-}min/L$$

This is the value that would be recorded by the system, which could then be compared to the CT tables to determine the level of virus treatment. This is also the value that would be transmitted to the Virus Treatment Determination Program (discussion follows).

Note that the difference between the generated CT value of 5.6 mg-min/L and the required CT of 4 is a result of the 0.5 mg/L safety margin. If no safety margin was provided (i.e., if the provided chlorine residual was 1.25 mg/L), then the CT Calculation Program would yield:

$$CT = \{(1.25\ mg/L) \times (0.3) \times [10\ ft \times 10\ ft \times 5\ ft) \times 7.48\ gal/ft^3)]\} / (351\ gpm) = 4.0\ mg\text{-}min/L$$

Log Treatment Determination and Documentation

The virus treatment determination program would consider the CT value calculated by the CT Calculation Program and the observed pH and temperature signals, and compare these values against the CT tables and, using a lookup function, determine and record the level of virus treatment from the tables. As an example, consider again the case illustrated in Figure 10 and described above, where the CT value was calculated and recorded as 5.6 mg-min/L. If, at that point in time, the following conditions were observed by the monitoring devices:

[PAT, ITALICS BELOW AND IN LINE 2]

pH =	7.5
Temperature =	15 degrees C

Then the Virus Treatment Determination Program would compare the CT, temperature, and pH values against the CT tables, and based on Table B-1 in the *Guidelines*, report and record the level of virus treatment of 4, because the provided CT was in excess of the maximum value of 4 in the 15 degree column of Table B-1.

Of course, there are limitations on the feasibility of applying an automatic CT-based disinfectant feed system, not the least of which is that it would probably not be consistent with current regulatory policy. Also, the introduction of additional monitoring instruments and control signals into the disinfectant feeder pacing algorithm introduces additional potential sources of failure. From a practical standpoint, most plants maintain a relatively constant dose of chlorine to the process for the sake of simplicity and consistency. In any case, the total chlorine usage is related more to the target total residual leaving the plant, which in most cases will be in the 3.0 to 4.0 mg/L range (not exceeding the MCL of 4 mg/L), rather than the free chlorine residual level in the primary disinfection zone. Nevertheless, it is worth recognizing that the concept is at least technically feasible.

The on-line, continuous documentation of CT and level of log treatment would certainly be useful to any utility using chemical disinfection to meet the subject requirements. This could be implemented independently of the feeder pacing system, and would be useful to plant operating staff in process optimization and troubleshooting and in demonstrating compliance to regulatory agencies.

Conclusion

The trade-off between the objectives of the D/DBP rule and the disinfection requirements under the GWR and the SWTR is well recognized, and the parameters that affect a utility's strategy for complying with both rules are generally well understood. There are numerous optimization opportunities that are relatively simple and reliable, and could be implemented with current technology. It should be recognized that as treatment processes and control systems become more sophisticated, there is a greater potential for optimization of the process with respect to these two rules.

Acknowledgments

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[3] *Guidelines*, pp. 1-1, 1-2.

[4] *Guidelines*, Table 2-1, pp. 2-2 - 2-6.

[5] *Guidelines*, p. 2-7.

[6] *Compliance Manual for Subpart H Systems*, Florida Department of Environmental Protection, June 2004, p. F.1.-3.

[7] *Guidelines*, p. 2-8.