STATE OF CONNECTICUT DEPARTMENT OF PUBLIC HEALTH
DRINKING WATER SECTION

TECHNICAL GUIDELINES FOR DETERMINING DISINFECTION "CT" WHEN USING CHLORINE FOR CHLORINATION OF GROUNDWATER SOURCES OF SUPPLY

Effective Date: February 1, 2008

Authority: Section 19-13-B102(d)(2) of the Regulations of Connecticut State Agencies (RCSA) requires approval from the Department of treatment works prior to construction. In addition, Section 19-13-B80 of the RCSA requires the review and approval by the Department of plans and specifications for any chemical treatment system. The following guidance is provided in the interest of facilitating the approval process. Discretion in the application of these guidelines is allowable except as required by regulation.

These guidelines and regulations, are subject to change in the future based on the Groundwater Rule which will have a compliance date of December 1, 2009. Public Water Systems (PWS) designing chlorination systems should take into consideration any requirements that may be imposed by the Groundwater Rule for each specific PWS. For more information please refer to EPA's Groundwater Rule website at http://www.epa.gov/safewater/disinfection/gwr/index.html.

Definitions

(1) Chlorination: in these guidelines means the use of chlorine, sodium hypochlorite, or calcium hypochlorite for disinfection. Chlorine dioxide and chloramines are not covered in these guidelines. These guidelines are primarily intended to only cover disinfection of groundwater sources of supply and not surface water or groundwater under the direct influence of surface water although some sections may be applicable to disinfection of all sources of supply.

(2) CT: per Section 19-13-B102(a)(22) of the RCSA "means the product of the residual disinfectant concentration (C) in milligrams per liter (mg/l) determined before or at the first customer, and the corresponding disinfectant contact time (T) in minutes (i.e., "C" X "T")." CT is typically expressed as mg-min/L (milligrams per minute per liter).

Dosage and Residual

(1) For surface water and groundwater under the direct influence of surface water, Section 19-13-B102(e)(7)(M) of the RCSA requires that water entering the distribution system be exposed to disinfection in accordance with Section 19-13-B102(j)(3)(B) of the RCSA. The requirements of these regulations are not covered in these guidelines.

(2) For chlorinated groundwater not under the direct influence of surface water, Section 19-13-B102(e)(7)(M) of the RCSA requires a minimum free chlorine residual of at least 0.2 mg/L after 10 minutes of contact time or equivalent. The product of free chlorine residual and contact time is known as CT. Therefore, the minimum required CT is 2 mg-min/L (i.e. 0.2 mg/L X 10 minutes). This CT value must be achieved at or before the first customer as noted in the definition for CT. Note that a higher free chlorine residual and lower contact time may be used to meet the required CT. For example, a free chlorine residual of 0.4 mg/L in conjunction with a contact time of 5 minutes will still satisfy the CT requirement of 2 mg-min/L (i.e. 0.4 mg/L X 5 minutes = 2 mg-min/L).

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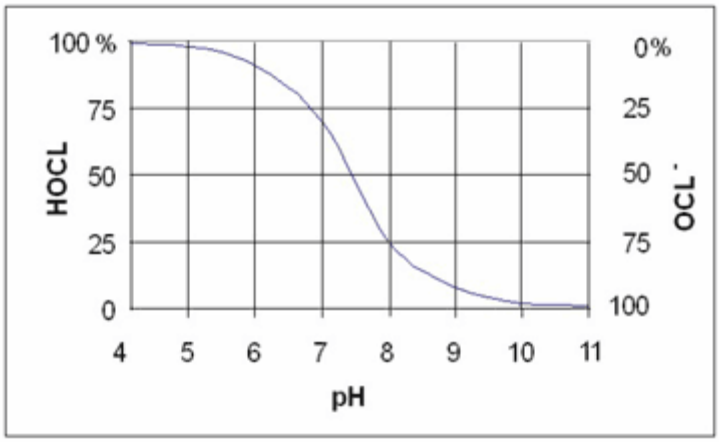
Note: under the Groundwater Rule requirements if 4-log virus inactivation treatment is mandated using only chlorination, the corresponding required CT will be approximately 6 mg-min/L depending on water temperature and pH.

(3) In determining the chlorine dosage for groundwater sources of supply, it is important that the pH of the water be analyzed. The reaction between chlorine and water forms hypochlorous acid (HOCl) which further separates (disassociates) into hydrogen (H^+) and hypochlorite (OCl^-) ions. The chemical equation for this reaction is:

$$HOCl \leftrightarrow H^+ + OCl^-$$

HOCl is a much more effective disinfectant than OCl^-, and the amount of HOCl present is dependent on pH as shown in the following disassociation curve:



As seen from the curve, at a pH of approximately 7.5 the percentage of HOCl and OCl^- is 50% each. At a pH greater than 7.5 the percentage of OCL^- dominates which results in a less effective disinfectant. Therefore, pH values greater than 7.5 may necessitate a higher chlorine dosage or contact time to provide effective disinfection, and a minimum CT of 4 mg-min/L is recommended. PWS that raise pH as part of a corrosion control program should pay particular attention to the effects of higher pH and the effect on disinfection. In such cases the pH adjustment point may need to be relocated after the addition of chlorine.

(4) A chlorine demand test should be performed in accordance with *Standard Methods for the Examination of Water and Wastewater* to determine the initial chlorine dosage. It is important to note that inorganic compounds found in groundwater such as iron, manganese, and sulfides will initially reduce the chlorine residual (i.e. create a chlorine demand), and these must be accounted for when determining the initial dosage. In lieu of performing a chlorine demand test, small PWS can use the following more general method as a rough estimate for the initial chlorine dosage:

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$$\text{chlorine dosage (mg/l)} = (\text{chlorine residual in mg/l}) + (\text{mg/l of Fe}) + (\text{mg/l of Mn}) + (\text{mg/l of } H_2S \text{ x } 4)$$

(5) Section 19-13-B102(e)(7)(M) of the RCSA requires that daily free chlorine residual readings be taken once chlorination is in active service. It is recommended that pH readings also be taken daily. Free chlorine residual readings shall be taken from a location that is representative of the minimum required contact time necessary to achieve CT at or before the first customer. The free chlorine residual at the sample location shall be sufficient such that a minimum CT of 2 mg-min/L is achieved at or before the first customer in accordance with Section 19-13-B102(e)(7)(M).

Sample lines may be used to demonstrate equivalency of contact time, however, the contact time in the sample line must be at least equivalent to the required contact time at or before the first customer. In cases where the contact time in a sample line is greater than the contact time required at or before the first customer, the same free chlorine residual that is required to achieve CT at or before the first customer must still be maintained at the sample location. The following two examples illustrate the requirements of this subsection:

> Example 1) It is determined that the contact time from the chlorination point to the first customer is 10 minutes, and therefore, a minimum free chlorine residual of 0.2 mg/L is required to be maintained at the first customer location. A sample line is installed with an equivalent contact time of 10 minutes. Therefore, the minimum free chlorine residual reading at the sampling location must be 0.2 mg/L.
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> Example 2) It is determined that the contact time from the chlorination point to the first customer is 5 minutes, and therefore, a minimum free chlorine residual of 0.4 mg/L is required to be maintained at the first customer location. A sample line is installed with a contact time of 10 minutes, and the PWS proposes to maintain a minimum free chlorine residual at the sampling location of 0.2 mg/L. In this case the minimum free chlorine residual of 0.2 mg/L would not be accepted, and a minimum free chlorine residual of 0.4 mg/L would need to be maintained at the sampling location.

To ensure that the minimum required equivalent contact time is maintained in the sample line, flow restrictors should be installed on the sample line.

Whenever possible, continuous chlorine analyzers and recorders with integrated alarms to indicate low and high free chlorine residual levels should be installed.

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Contact Time

(1) Adequate contact time is critical to ensure that the applied chlorine has adequate time to provide effective kill/inactivation of pathogenic organisms that may be present in the water. Contact time is typically achieved in a storage or contact tank following the chlorine application and may also be achieved in pipelines depending on the location of the first customer. Theoretical contact time is calculated as follows:

$$T = \frac{V}{Q}$$

T = contact time in minutes
V = volume of storage facility or pipe in gallons
Q = maximum flow rate in gpm

(2) Since poor circulation (i.e. short circuiting) in a storage or contact tank will reduce the contact time, T as calculated above is typically multiplied by a conversion or baffling factor to account for poor circulation. The diagrams on the following page show typical types of storage tanks, inlet/outlet pipe configurations, and corresponding recommended baffling factors (BF):

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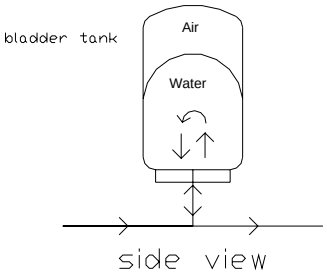
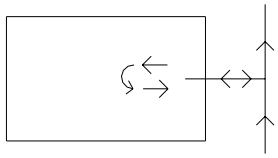
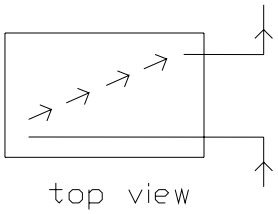
BF = 0

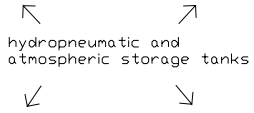


BF = 0

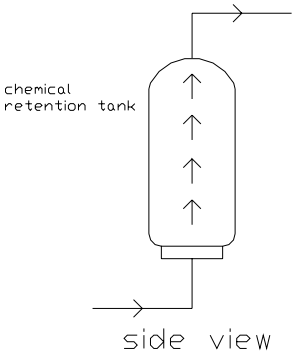


BF = 0.1 - 0.3[1]

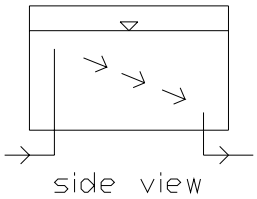




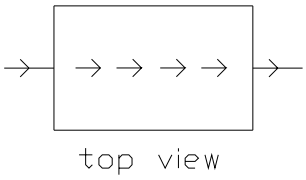
BF = 0.3



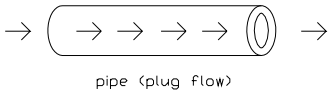
BF = 0.1 - 0.3[1]



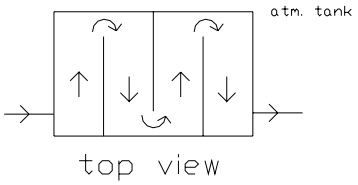
BF = 0.3



BF = 1.0



BF = 0.5 - 0.7[2]



Note that bladder tanks and atmospheric or hydropneumatic tanks with a single inlet and outlet are not given contact time credit since during a pump-on cycle, some of the water is bypassing the tank.

Footnotes:
[1] The recommended BF for tank configurations with separate inlets and outlets is 0.1 if the inlet pipe is not extended in the tank and up to 0.3 if the inlet pipe is extended as far in the tank as possible.
[2] See table on following page.

(3) For configurations not shown above, the following table can be utilized for recommended baffling factors:

Baffling Condition	Baffling Description	Baffling Factor
Unbaffled	Mixed flow, very low length-to-width ratio, high inlet and outlet flow velocities	0.1
Poor	Single or multiple unbaffled inlets and outlets, no intrabasin baffles	0.3
Average	Baffled inlet or outlet with some intrabasin baffles	0.5
Superior	Perforated inlet baffle, serpentine or perforated intrabasin baffles	0.7
Perfect	Plug flow; very high length-to-width ratio (pipeline flow), perforated inlet, outlet, and intrabasin baffles	1.0

Note: Table taken from EPA *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual*

(4) If a baffling factor is proposed that is higher than the recommended values, a tracer study should be conducted to confirm the proposed baffling factor. In the absence of a tracer study, supporting justification from the tank manufacturer or equivalent should be provided.

Calculating CT:

The following procedure explains how to determine if adequate CT is provided:

(1) Determine the total contact time available from the point of chlorine injection to the first customer during the maximum expected flow rate.

(a) for pipes, contact time is calculated as follows:

$$T = \frac{\left(0.785d^2\right) \times \left(L\right) \times \left(7.48\right)}{Q}$$

T = contact time in minutes
d = pipe diameter in feet
L = length of pipe in feet
Q = maximum expected flow rate in gpm

Note that for pipes, the baffling factor is 1.0. In cases where the well discharge piping tees into a water main causing the flow to split prior to the first customer, it must be assumed, in the absence of any supporting information, that all of the flow from the well is in one direction at

the tee towards the first customer. A hydraulic model or equivalent supporting information may be used to justify a more accurate flow rate split.

(b) for storage tanks, contact time is calculated as follows:

$$T = \left(\frac{V}{Q}\right) \times BF$$

T = contact time in minutes
Q = maximum expected flow rate through the tank in gpm
BF = baffling factor from Contact Time section above. Note that bladder tanks and atmospheric/hydropneumatic tanks with a common inlet/outlet cannot be used for chlorine contact time.
V = volume of tank at lowest normal operating water level in gallons. Note: this is not the gross volume of the tank unless the tank is a "flow through" type pressure contact vessel where the entire gross volume of the tank is water.

For hydropneumatic tanks with separate inlets and outlets, V can be calculated by the following procedure which is based on Boyle's Law:

$$V_{NU} = 100 - \left[\left(\frac{P_2 + 14.7}{P_1 + 14.7} - 1\right)(100 - V_W) + (100 - V_W)\right]$$

V_{NU} = non-usable water as percentage of total tank volume
P_1 = cut-in pressure in psi
P_2 = cut-out pressure in psi
V_W = percentage of total water in tank at P_2 in relation to total tank capacity (may be estimated using a sight tube for existing tank installations)

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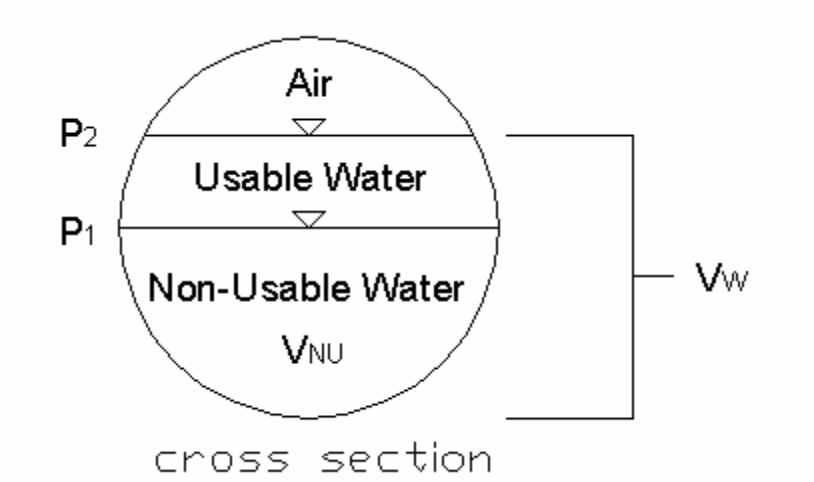

V in gallons can then be calculated as follows:

$$V = \left(\frac{V_{NU}}{100}\right) \text{ x Gross Volume of Tank}$$

If the above procedure is not utilized to calculate V in a hydropneumatic tank, supporting information/calculations will be required to justify an alternative V calculation.

(c) add up the total contact time available in minutes.

(2) Calculate CT provided as follows:

$$CT = (C) \times (T)$$

CT = mg-min/L
C = target free chlorine residual in mg/L
T = total contact time provided in minutes (from step 1 above)

(3) If the CT provided value in step (2) above is greater than or equal to 2 mg-min/L, then the CT provided is adequate.

(4) In lieu of step (3), the minimum free chlorine residual required can be calculated as follows:

$$C = \frac{2 \text{ mg - min/L}}{T}$$

C = minimum free chlorine residual required in mg/L
T = total contact time as calculated in step (1)

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(5) If CT provided as calculated in step (2) is less than 2 mg-min/L, the following two options may be considered acceptable:

(a) increase the target free chlorine residual as practically feasible and taking into account DBP formation potential as well as taste and odor concerns.

(b) increase the contact time by modifying existing or adding more storage tank(s). In some cases adding a pipe loop may provide the additional contact time needed. Note that any piping prior to the first customer may be used in chlorine contact time calculations.

(6) Note that the CT required of 2 mg-min/L as used in the above calculations may need to be increased to 4 mg-min/L or greater if the pH of the water to be treated is greater than 7.5 to provide effective disinfection.