**Instructions for Calculating Log Inactivation of *Giardia* Cysts**

**(also known as “CT Calculations”)**

The objective of these instructions is to help certified operators determine log inactivation of *Giardia* cysts at surface water treatment plants that use free chlorine as a disinfectant. **Conducting routine *Giardia* inactivation calculations is a critical step to ensuring compliance with PA Safe Drinking Water Regulations. Chapter 109 SDW regulations require: that the combined total effect of disinfection processes utilized in a filtration must achieve at least 1.0-log inactivation of Giardia cysts and 4.0-log treatment of viruses; and that the disinfectant residual at the entry point be maintained at or above 0.20 ppm.**

**Under the Disinfection Requirements Rule (DRR), failure to maintain the minimum log inactivation for more than 4 hours of operation is a breakdown in treatment that triggers 1-hour reporting to DEP and requires a Tier 1 Public Notice (likely in the form of a Boil Water Advisory). Additionally, under the DRR, failure to maintain the entry point disinfectant residual at or above 0.20 ppm for more than 4 hours of operation is a treatment technique violation that triggers 1-hour reporting to DEP and requires a Tier 2 Public Notice.**

**In order to maintain compliance with these requirements, operators should continuously monitor chlorine and calculate log inactivation of** *Giardia* **as often as possible in order to identify and remedy a reduction in *Giardia* inactivation before a regulatory violation occurs. Maintaining historical records is also required, and reporting the lowest daily log inactivation of giardia is required beginning no later than May 11, 2018.**

**If you are a public water system that treats a surface or ground water under the direct influence of surface water(GUDI) source, these requirements apply to you!**

Page two, the Basic Instructions for Calculating Log Inactivation of *Giardia*, provides a simplified 11‑step outline of the process required to calculate inactivation of *Giardia*. Note that this single page outlines the entire process; therefore, it is possible to successfully calculate log inactivation using only this page, and the reference table (*CT Values for 1-Log Inactivation of Giardia Cysts by Free Chlorine*) on page 8. However, due to the complexity of the process, additional instructions have been included (please see pages 3-7) to further explain each of the 11 steps. Finally, page 9 provides a completed example calculation, which summarizes the entire process using actual data from “XYZ Water Plant.”

The following instructions were designed for those who do not have routine access to a computer, prefer not to use a computer, or wish to learn the mathematical calculations. Please note that the following instructions only check for *G*. *lamblia* inactivation with free chlorine; *they do not include an analysis for viruses or other disinfectants*.

However, an electronic *Giardia* inactivation calculation spreadsheet (excel spreadsheet) is available, which contains embedded macros that automatically perform the calculations. The Excel spreadsheet allows calculation of *Giardia* and virus inactivation with various disinfectants including Free Chlorine, Chlorine Dioxide, Chloramines, and Ozone. This spreadsheet can be accessed at: <https://bit.ly/2HrO5JS>

*Basic Instructions for Calculating*

*“Log Inactivation of Giardia”*

1) Enter the system’s **peak hourly flow rate**       (*gpm).*

*\*Please see “Notes for steps 2,3 & 4” located on page 3 under “additional instructions” before performing these steps.*

2) Enter the **effective volume** of the disinfection segment       (*gal*).

 \**If tracer study data exists, you can skip steps 3 & 4 and enter the T10 value of the tracer study on line 5.*

3) Enter the **baffling factor** for the disinfection segment       .

4) Multiply the effective volume on line 2 by the baffling factor on line 3 to get the **corrected volume** and enter the result here       (gal).

5) Divide the corrected volume on line 4 by the peak hourly flow rate on line 1 to get the **T10 value**. Enter your results here       (min).

6) Enter the **free chlorine residual** concentration for the disinfection segment

      (*mg/L*) **C**

7) Multiply the T10 value on line 5 by the C value on line 6 to get the **CTactual** value. Enter the results here       .

8) Enter the **pH** value for the disinfection segment       .

###### 9) Enter the temperature for the disinfection segment       *(°C*).

10) Using the chlorine residual from line 6, the pH from line 8 and the temperature from line 9, determine the **CT1-log *Giardia***value from the tables located under *Additional Instructions for Step #10*. Enter the value here      .

11) Divide CT actual from line 7 by CT1-log *Giardia* from line 10 to get the “**log**” **inactivation value***.* Enter the results here       **log inactivation**.

 *If multiple disinfection segments exist, please repeat steps 1-11 for each disinfection segment. To get total log inactivation, add the log inactivation of all applicable disinfection segments together.*

***Additional Instructions***

##### ***Step #1* (Peak Hourly Flow Rate)**

The peak hourly flow occurs when the greatest volume of water flows through the system during any one hour in a 24-hour period. This value must be in gallons per minute (gpm). To convert gallons per day (gpd) to gpm divide by 1440. To convert million gallons per day (MGD) to gpm multiply by 694.4.

*For example: If a plant is producing 700,000* *gpd during its peak hour of production the peak flow is 700,000* *÷ 1440* *or 486* *gpm. You could also say that this same plant produces .7MGD; in this case the peak flow is .7 x 694.4 or 486 gpm. Round any decimals to the nearest whole number.*

***Notes for Steps 2, 3, & 4***

A disinfection segment begins at the point of disinfection application and ends at the disinfection residual sampling point. Flow rates used for these calculations should be measured at the point where water leaves / exits the disinfection segment.

For situations where one disinfection segment contains multiple basins with different baffling factors, multiply the effective volume of each basin by its corresponding baffling factor to get the corrected volume. Add the corrected volumes of each basin together and enter the results on line 4.

# ***Step #2* (Calculating Effective Volume)**

The effective volume of the disinfection segment refers to the volume of a basin or pipeline that is available to provide adequate contact time for the disinfectant. Effective volumes are calculated based on worst case operating conditions using the minimum operating depths in the case of basins.

*Choose the formula below which represents the disinfection segment for which you wish to calculate effective volume; then, simply plug in the dimensions and work through the equation. Note that your final answer must be in gallons.*

## *A. Rectangular Contactor* (l x w x d)

1) Enter length       (ft). **l**

2) Enter width       (ft). **w**

3) Enter depth of water       (ft). **d**

4) Multiply the length on line 1 by the width on line 2 by the depth on line 3 to get the volume in cubic feet       (ft³).

5) Multiply the volume in cubic feet on line 4 by 7.48 gal/ft³ to get effective volume in gallons       (gal). *Round any decimals to the nearest whole number; enter this value on line two of the Basic Instructions sheet.*

***B.******Cylindrical Contactor*** (**π r² d**)

1) π = 3.14

2) Enter radius       (ft). **r**

3) Multiply line 2 by line 2 to get **r²**. Enter the results here       (ft2). **r²**

4) Enter depth of water       (ft). **d**

5) Multiply 3.14 by **r²** on line 3 then multiply by the depth on line 4 to get the volume in cubic feet. Enter the results here       (ft³).

6) Multiply the volume in cubic feet on line 5 by 7.48 gal/ft³ to get effective volume in gallons       (gal). *Round any decimals to the nearest whole number; enter this value on line two of the Basic Instructions sheet.*

***C.******Pipeline* (.0408 x d²)**

1) Enter the pipe diameter here       (inches). **d**

2) Multiply line 1 by line 1 to get **d²**. Enter the results here       (in.²). **d²**

3) Multiply the **d²** on line 2 by .0408 to get gallons per foot. Enter the result here
      (gal/ft).

4) Multiply the number of feet in your pipeline by line 3 to get the effective volume of your pipeline       (gal.). Note: There are 5,280 ft. in a mile. *Round any decimals to the nearest whole number; enter this value on line two of the Basic Instructions sheet.*

#### *Step #3* (Determining Baffling Factor)

Tracer studies provide the most accurate information about disinfection contact times. If tracer studies are used, make sure that the T10 value from your tracer study coincides with your peak hourly flow rate. For those plants where tracer studies have not been conducted, the volume upon which contact time will be determined can be calculated by multiplying the effective volume, calculated on line two, by a factor (the baffling factor). Baffling factors should be assigned by an experienced professional engineer. Once assigned, baffling factors should NOT be changed by an operator, unless a tracer study is conducted and a new baffling factor is approved. These volumes are based on worst case operating conditions. For example, an unbaffled clearwell may have an effective volume of only 10 percent (baffling factor = 0.1) of actual basin volume because of the potential for short-circuiting; whereas, a transmission line could be achieve plug flow characteristics and be assigned a baffling factor between 0.9 and 1.0 (90 % to 100%).

A summary of factors to determine corrected volume is presented in the table below. Typically, for unbaffled clearwells a factor of 0.1 has been used because of the fill and draw operational practices (e.g., backwashing, demand changes). A factor of 0.3 has been used when calculating the corrected volume of flocculation and sedimentation basins when rating prechlorination, and a factor of 1.0 has been used for pipeline flow. However, each disinfection system must be assessed on individual basin characteristics, as perceived by the evaluator. Caution is urged when using a factor, from the table below, of greater than 0.1 to project additional disinfection capability for unbaffled basins. [1]

\*Factors for Determining Effective Disinfection Contact Time Based on Disinfection Segment Characteristics:

|  |  |  |
| --- | --- | --- |
| **Baffling Condition** | **Factor** | **Baffling Description** |
| Unbaffled | 0.1 | None; agitated basin, high inlet and outlet flow velocities, variable water level |
| Poor | 0.3 | Single or multiple unbaffled inlets and outlets, no intra-basin baffles |
| Average | 0.5 | Baffled inlet or outlet with some intra-basin baffling |
| Superior | 0.7 | Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated weir |
| Excellent | 0.9 | Serpentine baffling throughout basin |
| Perfect (plug flow) |  1.0 | Pipeline flow |
| \*Based on hydraulic detention time at minimum operating depth. |

[1]

***Step #4* (Corrected Volume)**

Line two x Line three

*For example, if a clearwell holds 90,000 gallons and the baffling factor is 0.1, the corrected volume is 90,000 gal x 0.1 or 9,000 gal. Round any decimals to the nearest whole number.*

***Step #5* (T10 value)**

T10 represents the time that 90 percent of the water, including the microorganisms within the water, will be exposed to disinfection within the disinfectant contact chamber.

(Line 4) / (Line 1) = T10 or Line 4 = T10

 Line 1

*For example, if a clearwell has a corrected volume of 9000 gal and the peak hourly flow rate is 486 gpm, the T10 value would be 9000 gal /486 gpm or 19 min. Round any decimals to the nearest whole number.*

***Step #6* (Free Chlorine Residual Concentration)**

The free chlorine residual concentration is the amount of chlorine in the water that has not reacted/combined with any organic materials or compounds. This is different than total chlorine residual which is the sum of the combined and free chorine residuals. The free chlorine residual should be routinely monitored at the end of the disinfection segment(s) used for inactivation credit. Installation of a continuous chlorine analyzer and recording device after each disinfection segment is likely required by your regional DEP office. *Note that both pH and temperature values will need to be recorded at this same sampling point; these values will be needed for later reference. This number must be in milligrams per liter (mg/L). Note that parts per million (ppm) is equal to mg/L. When conducting manual calculations, always round this value down to the nearest tenth. For example, 1.09 mg/L would be rounded down to 1.0 mg/L and 1.79 mg/L would be rounded down to 1.7 mg/L.* If using the Excel spreadsheet calculation tool, you may enter the specific free chlorine residual value without rounding.

***Step #7* (CT actual value)**

(line 5) (line 6) = CT actual or Line 5 **X** Line 6 = CT actual

*For example, if a clearwell has a T10 value of 19 minutes and an entry point (end of clearwell) free chlorine residual of 1.3 mg/L, then the CT actual is 19 x**1.3, or 24.7 mg/L-min. When conducting the manual calculation, round results so that only one number appears after the decimal.*

***Step #8* (pH)**

pH should be measured at the same sampling point as the free chlorine residual. When conducting manual calculations, always round the pH value up to the nearest .5 or .0 *For example a pH of 7.2 should be recorded as 7.5; and, a pH of 6.7 should be recorded as 7.0*. If using the Excel spreadsheet calculation tool, you may enter the specific pH value without rounding.

***Step #9* (Temperature)**

Temperature should be measured at the same sampling point as the free chlorine residual. When conducting manual calculations, always round the temperature value down to the nearest of the following values: 5°C, 10°C, 15°C, 20°C, or 25°C. For example, a temperature of 13°C would be recorded as 10°C. Any temperature that is less than 5°C should be recorded as <=0.5°C. Note that the temperature must be recorded in °C. To convert Fahrenheit to Celsius, subtract 32 and then multiply by 0.555; or 0.555(°F – 32) = °C. *For example, if your water temperature is 47°F, you would have 0.555(47-32) = 8.3°C, which would be rounded down to 5°C.* If using the Excel spreadsheet calculation tool, you may enter the specific temperature value without rounding.

***Step #10* (Determining CT1-log *Giardia*)**

The reference table located on the page 8 is arranged in order of increasing temperature (°C). To use these tables, begin by locating your temperature (from line nine) on the top of one of the tables. On this same table, locate your pH value (from line eight). Make a light pencil mark through the entire column below your pH. Next, locate your chlorine residual concentration (from line six). To be conservative, choose from the chart a chlorine residual that is rounded to the next highest even tenth. For example, if your chlorine residual was 1.2 mg/L, choose 1.2 mg/L from the chart. If your chlorine residual was 1.1 mg/L, choose 1.2 mg/L from the chart. Make a light pencil mark through the entire row located to the right of your chlorine concentration. Finally, follow both pencil lines until the two intersect. This is your CT1‑log *Giardia*value, *enter this value on line ten of the Basic Instructions sheet. Interpolation between values listed on this chart is allowed. Therefore, if you are familiar with the process of interpolation and wish to do so, you may.* The excel spreadsheet will automatically reference this table and perform interpolation calculations for you.

Step #11

**Line 7 ÷ Line 10 or Line 7**

 **Line 10**

***Round results so that only two numbers appear after the decimal. For example, if the*** **CTactual *is 120 and the CT1-log Giardia is 43, then the log inactivation is 120 ÷ 43 = 2.79 logs***

***CT Values for 1-Log Inactivation of Giardia Cysts by Free Chlorine***

|  |  |  |  |
| --- | --- | --- | --- |
| **Chlorine Concentration (mg/L)** | **Temperature <=0.5***°***C** | **Temperature =5***°***C** | **Temperature = 10***°***C** |
| **pH** | **pH** | **pH** |
| **<=6.0** | **6.5** | **7.0** | **7.5** | **8.0** | **8.5** | **9.0** | **<=6.0** | **6.5** | **7.0** | **7.5** | **8.0** | **8.5** | **9.0** | **<=6.0** | **6.5** | **7.0** | **7.5** | **8.0** | **8.5** | **9.0** |
| **<=0.4** | 46 | 54 | 65 | 79 | 92 | 110 | 130 | 32 | 39 | 46 | 55 | 66 | 79 | 93 | 24 | 29 | 35 | 42 | 50 | 59 | 70 |
| **0.6** | 47 | 56 | 67 | 80 | 95 | 114 | 136 | 33 | 40 | 48 | 57 | 68 | 81 | 97 | 25 | 30 | 36 | 43 | 51 | 61 | 73 |
| **0.8** | 48 | 57 | 68 | 82 | 98 | 118 | 141 | 34 | 41 | 49 | 58 | 70 | 84 | 100 | 26 | 31 | 37 | 44 | 53 | 63 | 75 |
| **1** | 49 | 59 | 70 | 84 | 101 | 122 | 146 | 35 | 42 | 50 | 60 | 72 | 87 | 104 | 26 | 31 | 37 | 45 | 54 | 65 | 78 |
| **1.2** | 51 | 60 | 72 | 86 | 104 | 125 | 150 | 36 | 42 | 51 | 61 | 74 | 89 | 107 | 27 | 32 | 38 | 46 | 55 | 67 | 80 |
| **1.4** | 52 | 61 | 74 | 89 | 107 | 129 | 155 | 36 | 43 | 52 | 62 | 76 | 91 | 110 | 27 | 33 | 39 | 47 | 57 | 69 | 82 |
| **1.6** | 52 | 63 | 75 | 91 | 110 | 132 | 159 | 37 | 44 | 53 | 64 | 77 | 94 | 112 | 28 | 33 | 40 | 48 | 58 | 70 | 84 |
| **1.8** | 54 | 64 | 77 | 93 | 113 | 136 | 163 | 38 | 45 | 54 | 65 | 79 | 96 | 115 | 29 | 34 | 41 | 49 | 60 | 72 | 86 |
| **2** | 55 | 66 | 79 | 95 | 115 | 139 | 167 | 39 | 46 | 55 | 67 | 81 | 98 | 118 | 29 | 35 | 41 | 50 | 61 | 74 | 88 |
| **2.2** | 56 | 67 | 81 | 99 | 118 | 142 | 170 | 39 | 47 | 56 | 68 | 83 | 100 | 120 | 30 | 35 | 42 | 51 | 62 | 75 | 90 |
| **2.4** | 57 | 68 | 82 | 99 | 120 | 145 | 174 | 40 | 48 | 57 | 70 | 84 | 102 | 123 | 30 | 36 | 43 | 52 | 63 | 77 | 92 |
| **2.6** | 58 | 70 | 84 | 101 | 123 | 148 | 178 | 41 | 49 | 58 | 71 | 86 | 104 | 125 | 31 | 37 | 44 | 53 | 65 | 78 | 94 |
| **2.8** | 59 | 71 | 86 | 103 | 125 | 151 | 181 | 41 | 49 | 59 | 72 | 88 | 106 | 127 | 31 | 37 | 45 | 54 | 66 | 80 | 96 |
| **3** | 60 | 72 | 87 | 105 | 127 | 153 | 184 | 42 | 50 | 61 | 74 | 89 | 108 | 130 | 32 | 38 | 46 | 55 | 67 | 81 | 97 |

|  |  |  |  |
| --- | --- | --- | --- |
| **Chlorine Concentration (mg/L)** | **Temperature = 15***°***C** | **Temperature = 20***°***C** | **Temperature = 25***°***C** |
| **pH** | **pH** | **pH** |
| **<=6.0** | **6.5** | **7.0** | **7.5** | **8.0** | **8.5** | **9.0** | **<=6.0** | **6.5** | **7.0** | **7.5** | **8.0** | **8.5** | **9.0** | **<=6.0** | **6.5** | **7.0** | **7.5** | **8.0** | **8.5** | **9.0** |
| **<=0.4** | 16 | 20 | 23 | 28 | 33 | 39 | 47 | 12 | 15 | 17 | 21 | 25 | 30 | 35 | 8 | 10 | 12 | 14 | 17 | 20 | 23 |
| **0.6** | 17 | 20 | 24 | 29 | 34 | 41 | 49 | 13 | 15 | 18 | 21 | 26 | 31 | 36 | 8 | 10 | 12 | 14 | 17 | 20 | 24 |
| **0.8** | 17 | 20 | 24 | 29 | 35 | 42 | 50 | 13 | 15 | 18 | 22 | 26 | 32 | 38 | 9 | 10 | 12 | 15 | 18 | 21 | 25 |
| **1** | 18 | 21 | 25 | 30 | 36 | 43 | 52 | 13 | 16 | 19 | 22 | 27 | 33 | 39 | 9 | 10 | 12 | 15 | 18 | 22 | 26 |
| **1.2** | 18 | 21 | 25 | 31 | 37 | 45 | 53 | 13 | 16 | 19 | 23 | 28 | 33 | 40 | 9 | 11 | 13 | 15 | 18 | 22 | 27 |
| **1.4** | 18 | 22 | 26 | 31 | 38 | 46 | 55 | 14 | 16 | 19 | 23 | 28 | 34 | 41 | 9 | 11 | 13 | 16 | 19 | 23 | 27 |
| **1.6** | 19 | 22 | 26 | 32 | 39 | 47 | 56 | 14 | 17 | 20 | 24 | 29 | 35 | 42 | 9 | 11 | 13 | 16 | 19 | 23 | 28 |
| **1.8** | 19 | 23 | 27 | 33 | 40 | 48 | 58 | 14 | 17 | 20 | 25 | 30 | 36 | 43 | 10 | 11 | 14 | 16 | 20 | 24 | 29 |
| **2** | 19 | 23 | 28 | 33 | 41 | 49 | 59 | 15 | 17 | 21 | 25 | 30 | 37 | 44 | 10 | 12 | 14 | 17 | 20 | 25 | 29 |
| **2.2** | 20 | 23 | 28 | 34 | 41 | 50 | 60 | 15 | 18 | 21 | 26 | 31 | 38 | 45 | 10 | 12 | 14 | 17 | 21 | 25 | 30 |
| **2.4** | 20 | 24 | 29 | 35 | 42 | 51 | 61 | 15 | 18 | 22 | 26 | 32 | 38 | 46 | 10 | 12 | 14 | 17 | 21 | 26 | 31 |
| **2.6** | 20 | 24 | 29 | 36 | 43 | 52 | 63 | 15 | 18 | 22 | 27 | 32 | 39 | 47 | 10 | 12 | 15 | 18 | 22 | 26 | 31 |
| **2.8** | 21 | 25 | 30 | 36 | 44 | 53 | 64 | 16 | 19 | 22 | 27 | 33 | 40 | 48 | 10 | 12 | 15 | 18 | 22 | 27 | 32 |
| **3** | 21 | 25 | 30 | 37 | 45 | 54 | 65 | 16 | 19 | 23 | 28 | 34 | 41 | 49 | 11 | 13 | 15 | 18 | 22 | 27 | 32 |

*“Summary Example Giardia Inactivation Calculations for XYZ Water Plant”*

1) Enter the system’s **peak hourly flow rate** **1*,*076** (*gpm).*

**(1*.*55 MGD) (694*.*4) = 1*,*076*.*32 gpm = 1*,*076 gpm**

2) Enter the **effective volume** of the disinfection segment **240*,*018** (*gal*).

**Rectangular clearwell (66*.*85’)(40’)(12’) = 32*,*088 cu. ft.**

**32*.*088 cu. ft. (7*.*48 gal/cu. ft.) = 240*,*018*.*24 gal = 240*,*018 gal.**

3) Enter the **baffling factor** for the disinfection segment ***.*5** .

**Baffled inlet with some intra-basin baffling**

4) Multiply the effective volume on line 2 by the baffling factor on line 3 to get the **corrected volume** for the disinfection segment and enter the result here **120*,*009** (*gal*).

**(240*,*018 gal) (*.*5) = 120*,*009 gal.**

5) Divide the corrected volume on line 4 by the peak hourly flow rate on line 1 to get the **T10** value. Enter your result here **112** (*min*).

**(120*,*009 gal)/(1*,*076 gpm) = 111*.*5 = 112**

6) Enter the **free chlorine residual** concentration for the disinfection segment **1*.*3** (*mg/L*).  **C**

 **1.31 rounded down to 1*.*3 mg/L**

7) Multiply the T10 value on line 5 by the C value on line 6 to get the **CTactual** value. Enter the results here **145.6** .

 **(112 min)(1*.*3 mg/L)= 145.6**

8) Enter the **pH** value for the disinfection segment **8.5**.

 **8*.*3 rounded up to 8*.*5**

###### 9) Enter the temperature for the disinfection segment 10 *(°C*).

 **12 °C rounded down to 10 °C**

10) Using the chlorine residual from line 6, the pH from line 8 and the temperature from line9, determine the **CT1-log *Giardia*** value from the tables located under *Additional Instructions for Step**#10*. Enter the value here **69**.

 **10°C, 8.5 pH, 1.3 mg/L chlorine residual (round to 1.4 to be conservative)**

1. Divide CTactual from line 7 by CT1-log *Giardia* from line 10 to get the **“log” inactivation value***.* Enter the results here **2.1**. This is your **“log” inactivation value.**

**(145.6)/(69)= 2.1**

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**REFERENCES**

[1] Bob A. Hegg, Larry D. DeMers, Jon H. Bender, Eric M. Bissonette, and Richard J. Lieberman, EPA Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program, M. Lynn Kelly, Process Applications, Inc., Fort Collins, Colorado (1998) pp. 33-35, 135‑141.