NSW GOVERNMENT | Department of Primary Industries | Office of Water

RECYCLED WATER | INFORMATION SHEET 8

Getting chlorination right

June 2015

Chlorination

Chlorine is a strong oxidising agent and is effective against bacteria and viruses, moderately effective against the protozoan parasite *Giardia,* but not effective for *Cryptosporidum*.

When chlorine is added to effluent a series of reactions occur that consume free chlorine.

Chlorination is the addition of chlorine liquid or gas to water to form hypochlorous acid (HOCl) and hydrochloric acid (HCl).

Primary kill is the main mechanism in which inactivation of pathogens (the log reduction value) is achieved.

Chlorine demand is the difference between the amount of chlorine added to a water system and the amount of free available chlorine or combined available chlorine remaining at the end of a specified time period.

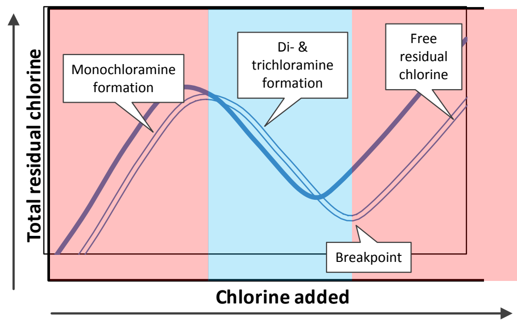
Free chlorine residual is the amount of chlorine which exists in the treated water system as hypochlorous acid and hypochlorite ions after the chlorine demand has been satisfied. Over time, chlorine will continue to oxidise substances in the recycled water. This chlorine decay may eventually result in no free chlorine residual in the recycled water.

Chloramination is the reaction of chlorine with any compound containing a nitrogen atom with one or more hydrogen atoms attached. Monochloramine is a stable and an effective disinfectant, whereas di- and tichloramine reduce disinfection power and result in odours. Chloramines are also known as combined chlorine.

Total chlorine is the sum of free and combined chlorine

Figure 1 depicts the formation of chloramines and shows the reaction of chlorine in the presence of ammonia. When all ammonia has been saturated, the *breakpoint* is reached where an increase in the total chlorine concentration rises again. This has important implications when assessing the disinfection capabilities of a system.

Figure 1 Breakpoint curve for chlorination and chloramination



Residual concentration and C.t

Disinfection by chlorination (or chloramination) has advantages over other disinfection techniques in that it offers effective primary kill of disease-causing pathogens as well as residual disinfection to protect against recontamination between supplier and recipient.

Concentration.time (C.t) is an important parameter which allows the operator to determine if sufficient primary kill is achieved. C.t is a function of the concentration of free chlorine residual (or chloramine), the occupied volume of the chlorine contact tank, flowrate and type of baffle; as follows:

$C.t = [Cl]_{residual} \times V/Q \times f$

Where:

- *C.t* - concentration time (mg-min/L)
- $[Cl]_{residual}$ - concentration of the chlorine (or chloramine; mg/L) at the outlet
- *Q* - flow rate into the inlet pipe (m^3/min)
- *V* – volume of contact tank (m^3)
- *f* – baffle factor (dimensionless unit between 0 – 1 which contributes to the degree of short-circuiting within the contact tank). See USEPA (1999) Appendix D.2.2: for more information.

It is essential for the ongoing confirmation of C.t that the online chlorine analyser is calibrated and operating correctly.

Determining disinfection effectiveness

A worked example to determine effective disinfection is given in Table 1.

Table 1 Steps to calculate effective disinfection

Step	Worked Example
1. Determine log reduction requirements	4 log virus removal requirement
2. From literature, determine corresponding required C.t	With a pH of 8 and NTU of 2 Required C.t=15.68 mg-min/L (refer Table 2)
3. Determine baffle factor (refer Table 3)	Unbaffled Baffle factor (f) = 0.1
4. Measure or determine average chlorine residual, flow rate and tank volume	Tank volume (V) = 300m^3 Flow rate (Q) = 6 m^3/min Chlorine residual = 0.4 mg/L
5. Calculate actual C.t	$\mathrm{C.t} = 0.4\mathrm{mg/L} \times \frac{300\mathrm{m}^3}{6\mathrm{m}^3/\mathrm{min}} \times 0.1$ C.t =2 mg-min/L
6. Compare actual C.t to required C.t	With an actual C.t lower than the required C.t. effective disinfection is not provided. Need to respond with additional treatment, better baffle and/or a higher chlorine residual.

Note: There is a variety of literature relating to concentration.time for disinfection against certain pathogenic microorganisms, under different conditions, refer to *More Information*.

Table 2 is an excerpt from Table 1E of the Smart Water Fund paper on chlor(am)ine disinfection. Design C.t are given for 1 and 4 $\log_{10}$ inactivations of CB5 virus, pHs and turbidities.

Table 2 Free chlorine C.t values for 1 and 4 log reduction of CB5 virus at various turbidity and pH levels

		Concentration.time (mg-min/L)		
pH	**Log reduction**	**0.2 NTU**	**2 NTU**	**20 NTU**
7	1	2.05	2.13	2.55
	4	5.44	5.46	25.81
8	1	5.72	6.67	7.99
	4	15.49	15.68	34.52
9	1	8.25	8.94	13.7
	4	23.97	26	51.89

Source: *Smartwater fund (2012)*

From Table 1, the following trends are observed:

- Higher log reduction requires longer contact times
- Increasing turbidity requires longer contact times
- Higher pH levels require longer contact times as the amount of available HOCl (formed by the reaction between chlorine and water) decreases as pH increases; shown in Figure 2.

Figure 2 Fraction of available hypochlorous (HOCl)

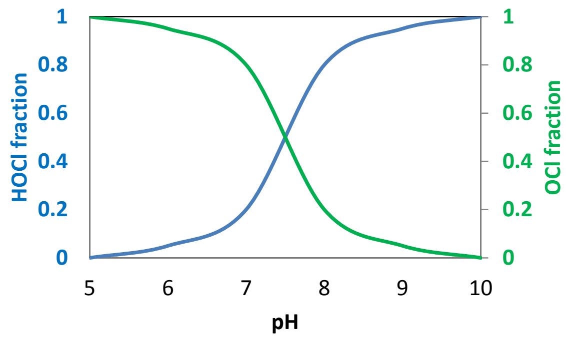


Table 3 Baffling Factors

Baffling Factor	Baffling Description
0.1	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities
0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles.
0.5	Baffled inlet or outlet with some intra-basin baffles.
0.7	Perforated inlet baffle, serpentine or perforated intrabasin baffles, outlet weir or perforated launders.
1.0	Very high length to width ratio, perforated inlet, outlet, and intra-basin baffles or flow within a pipe.

Source: *Table D-5, US EPA (1999)*

Where the C.t. is achieved in the supply pipeline the CCPs will need to consider the procedures to be followed if C.t is not achieved.

More information

Australian Guidelines for Water Recycling (2006)

Smart Water Fund. Alexandra Keegan, Satiya Wati & Bret Robinson. (2012). *Chlor(am)ine disinfection of human pathogenic viruses in recycled waters*. Table 1E. Page 5

Shamarie Black , Jeanette A. Thurston & Charles P. Gerba (2009) *Determination of Ct values for chlorine of resistant enteroviruses*, Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 44:4, 336-339.

US EPA. (1999) *EPA Guidance manual: Disinfection profiling and benchmarking*. Appendix C: CT values for inactivations achieved by various disinfectants. Appendix D.2.2: for information on baffling factors

For more information visit www.water.nsw.gov.au or contact: rwapprovals@dpi.nsw.gov.au

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