Appendix 11. A primer in disinfection characterization[1]

From technical and regulatory perspectives, water disinfection is routinely characterized on the basis of “contact time.” Contact time and its kinetics are simply a measure of the inactivation expressed as a function of concentration of the disinfectant and time (as C*t, is C, residual concentration, and t, time). Under the regulatory auspices of the SDWA as amended, EPA has developed regulations for the minimum kill percentages (inactivation) necessary for public water to be considered potable, including regulations that specify minimum disinfection of (1) 3 log (99.9%) for *Giardia lamblia* cysts and (2) 4 log (99.99%) for enteric viruses (see Letterman 1999, see also http://www.epa.gov/safewater/sdwa/index.html last accessed December 8, 2004).

Derivation of C*t values. A relationship between disinfection and contact time was originally described by Chick (1908 as cited in Haas 1999). Her research yielded data characterizing a relationship between survival and exposure to disinfectant illustrated Figure 1, where N_0 represents the initial number of organisms and N_t is the number of organisms at time *t*. As contact time between water and disinfectant increases, the ratio of (N_t / N_0) decreases, a general outcome subsequently referred to as “Chick’s Law.”

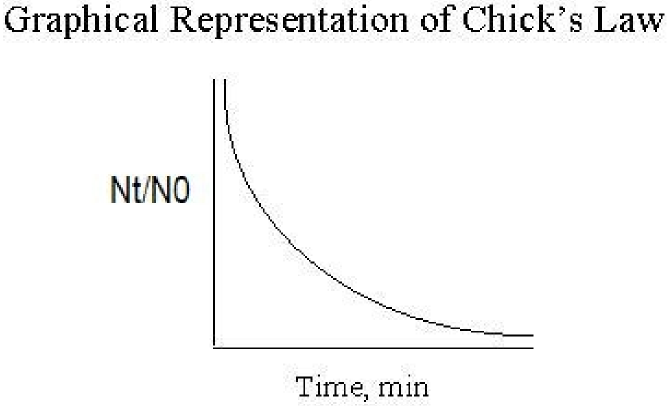

Figure 1. Typical plot of disinfection as measured by number of survivors exposed to C*t.

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[1] Original source, Daniel Gallagher, Eric Karch and David Loftis, Virginia Technological Institute and State University, Blacksburg, VA. Updated June, 2004.

Chick's relatively simple equation was subsequently modified to account for various disinfectants or disinfection methods (e.g., physicochemical and physical barrier technologies; Watson 1908 as cited in Haas 1999), originally yielding the formulation of Chick-Watson Law. For example, the relatively simple relationship that characterizes the exponential decay curve in Figure 1 is modified to incorporate coefficients that account for the varying strengths of "disinfectant" and the dependence of disinfection on physicochemical attributes of water, e.g., pH. In water treatment technology, the coefficient of specific lethality (λ, lambda) captures these attributes mathematically, yielding Watson's modification of Chick's equation for a constant-mixed batch reactor (see, e.g., Haas 1999):

$$\ln(N_t / N_0) = -\lambda c^n t$$

where

N_t = number of viable organisms at time t,
N_0 = number of viable organsims at time 0,
λ = coefficient of lethality,
c = concentration of disinfectant,
n = coefficient of media attributes (e.g., dilution, pH)
t = contact time (C*t; time elapsed between counts)

Factors affecting C*t.[2] Water quality characteristics will influence disinfection processes. For example, turbidity and pH strongly affect how long exposure must be in order to attain a desired rate of disinfection, e.g., as pH increases, the value of C*t must also increase in order to maintain a specific rate of disinfection ($\ln(N_t / N_0)$; see Table 1). For chlorination processes, this observation can be explained by noting the effects of pH on free chlorine. Similarly, as pH increases, the concentration of OCl^- (weak disinfectant) increases and $HOCl^-$ (strong disinfectant) decreases; thus, C*t must be increased to maintain a given rate of disinfection. Similarly, to

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[2] Units of contact time, C*t, are (mg/l)(min)

increase disinfection (i.e., increase rate of log removal), C*t needs to be increased if other parameters in the process are held constant.

Table 1. C*t for removal of *Giardia* cysts in relation to log removal and pH

Log Removal	**pH <6**	**pH 6.5**	**pH 7.0**	**pH 7.5**
1.0	46	54	65	79
1.5	69	82	98	119
2.0	91	109	130	158
2.5	114	136	163	198

Not surprisingly, disinfectant strength directly affects C*t, e.g., for a weak disinfectant, C*t will have to be greater than for a strong disinfectant. Ozone is the strongest disinfectant, and C*t for ozonation is less when compared to chlorine and chlorine dioxide. Microorganisms have varying sensitivities to disinfectants, and if an organism has a high resistance to a certain disinfectant, C*t will be greater than for an organism with a low resistance (see Table 2).

Table 2. C*t Values for 99% inactivation at 5°C for various organisms subjected to various disinfectants[3]

Organism	**Free Chlorine (pH 6-7)**	**Chlorine Dioxide (pH 6-7)**	**Ozone (pH 6-7)**
E.coli	0.034-0.05	0.4-0.75	0.02
Rotavirus	0.01-0.05	0.2-2.1	0.006-0.06
Giardia lamblia cysts	47-150	-	0.5-0.6
Crytosporidium parvum	7200*	79*	5-10*

* 99% inactivation at 25°C

Depending on the specifications of the treatment system (e.g., regulatory requirements), various

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[3] Hoff, J.C., Inactivation of microbial agents by chemical disinfectants, EPA/600/2-86/067, 1986

levels of disinfection can be attained by altering the type and concentration of disinfectant, and contact time. The selection of disinfection technology can be determined once regulatory and management needs are addressed, but once the level of disinfection is specified, then using the Chick-Watson relationship, engineering designs can be specified to yield the necessary contact time for a given level of disinfection. The time untreated water is exposed to the disinfectant and the concentration of that disinfectant are the main factors in the equation that influence management of water disinfection systems.

References

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