# Equivalent Public Health Protection? A Comparison of Chlorine and UV for Disinfection of Reclaimed Water

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## ABSTRACT

*When deciding on reclaimed water disinfection technology, cost is frequently the primary factor. Reclaimed water regulations, which specify ultraviolet light (UV) and chlorine dose, inadvertently drive cost-based decisions toward chlorination. Chlorine disinfection requirements are based on dated information; do not reflect the current understanding of chlorine chemistry; and may not meet pathogen disinfection standards at the regulated doses, depending on a range of water quality parameters. Unlike chlorine regulations, regulated UV dose targets meet indicator organism and pathogen disinfection targets, including those for viruses (5 logs of inactivation of enteric viruses using a poliovirus model) and protozoa. What is required in the industry is an understanding of the differences in pathogen disinfection of UV and of chlorine at the regulated dose levels. The end result would be a comparison of technologies that result in an equivalent low level of pathogen disinfection, and thus, an equivalent level of public health protection.*

**Key Words:** UV, ultraviolet light, chlorine, pathogens, disinfection, reclaimed water.

## INTRODUCTION

For wastewater disinfection, the primary drivers for technology selection are worker and public safety, cost, and the ability to meet indicator organism (bacterial) requirements. Reducing effluent toxicity (including disinfection by-products (DBPs)) and pathogen disinfection, while often listed in utility mission statements or goals, rarely govern disinfection process selection. If worker and public safety is an issue (related to the use of chlorine gas), most utilities will convert to sodium hypochlorite, and some will convert to ultraviolet light (UV) disinfection. If cost is the primary driver, and pathogen disinfection is not, chlorine will repeatedly be the disinfection technology of choice.

For reclaimed water disinfection, the disinfectant selection process becomes more complex. Some reclaimed water producers have stringent DBP requirements. If this is the case, UV or other non-chlorine technologies will be selected, regardless of cost. For certain reclaimed water providers, pathogen disinfection is of primary concern, not simply indicator organism destruction. In these cases, UV disinfection will be the technology of choice. Still, DBPs and pathogen disinfection rarely guide reclaimed water disinfection technology selection; cost remains the primary driver.

Though the intent of reclaimed water quality (or the disinfection barrier) regulations is pathogen inactivation, the framework of the regulations do allow for chlorine systems to be designed to a lower level of pathogen disinfection than the requirements for UV. It should be noted that regulated chlorine levels are intended as the minimum allowable levels for disinfection. Because of the common use of the minimum regulated dosing and contacting requirements, the costs for UV disinfection of reclaimed water are consistently higher than the costs for chlorine disinfection. The result is that the regulations are driving the selection and implementation of a technology with potentially inferior pathogen disinfection ability. This paper argues that reclaimed water quality regulations must incorporate the *real* differences in disinfection performance between chlorine and alternative disinfectants (particularly UV). An even more progressive approach, not detailed in this paper, is to examine the impact of integration of disinfection technology into the existing process train, that is, review the overall treatment process performance to meet regulatory disinfection objectives.

## Reclaimed Water Regulations

For reclaimed water intended for potential public contact applications, most states have strict coliform limits, with the underlying assumption that the destruction of the indicator organism results in the destruction of various pathogens of concern. Traditionally, coliforms have been a useful, though not perfect, surrogate indicator of process performance. Meeting the coliform standard consistently is an indication of a well-run wastewater treatment plant. Some states, including California, set chlorine disinfection and UV dose requirements. Others, like Florida, have sliding chlorine dose requirements based on influent fecal coliform concentrations and are now recommending the high UV dose requirements utilized in California. The majority of states rely on the utility to set dose requirements that will result in the regulated coliform levels.

Examples of reclaimed water regulations are shown in Table 1. The majority of reclaimed water use states expect pathogen free water, though treatment processes, where specified, may or may not meet this goal.

Florida has also established guidelines for *Giardia, Cryptosporidium*, and enterovirus in reclaimed water effluents (see Table 2), including periodic monitoring and reporting requirements.

**Table 1.** *Overview of Reclaimed Water Requirements for Several States*

| State | Bacteria | Virus/Protozoa | Required Chlorine *Ct* | Required UV Dose |
|---|---|---|---|---|
| CA "Tertiary Recycled" | 2.2 MPN/100mL Total Coliform | 5-log inactivation/kill virus expected, pathogen free water. | 450 mg-min/L | 100 mJ/cm$^2$, post media filter<br>80 mJ/cm$^2$, post membrane filter |
| TX "Type I Reclaimed" | 20 CFU/100mL Fecal Coliform | No standard | No standard, potential *Ct* needed >100 mg-min/L (Dietrich et al. 2003) | No standard, potential UV dose needed >25 mJ/cm$^2$ |
| FL "High Level Disinfection" | ND Fecal Coliform per 100mL | Pathogen free water expected | >10,000 fecal/100 mL – 120 mg-min/L<br><10,000 fecal/100 mL – 40 mg-min/L<br><1,000 fecal/100 mL – 25 mg-min/L | CA standards acceptable, lesser doses not approved at this time |

**Table 2.** *Florida Reuse Pathogen Guidelines (from FDEP 2003)*

| Pathogen | Units | Average | Maximum |
|---|---|---|---|
| *Giardia* | Viable Cysts/100L | 1.4 | 5.0 |
| Cryptosporidium | Viable Oocysts/100L | 5.8 | 22 |
| Enterovirus | PFU/100L | 0.044 | 0.165 |

### UV DISINFECTION PERFORMANCE

UV disinfection of reclaimed water is well proven in the industry and in the literature. Cosman and Wright (2000) summarized the dose/response literature for various microorganisms and pathogens of concern, clearly showing that UV disinfection meets reclaimed water disinfection pathogen standards at regulated dose values.

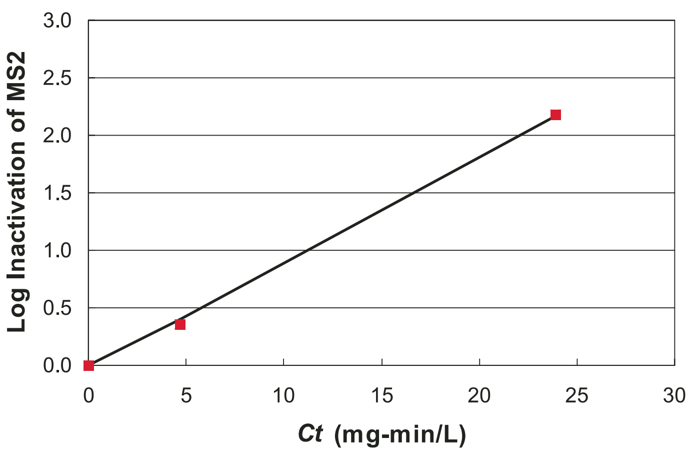
The key water quality issue that can impact UV disinfection performance is the existence of particle-associated organisms. Coliform organisms frequently become embedded in particulate matter, partially or wholly protecting them from the UV light (Parker and Darby 1995, Emerick et al. 1999, WERF 1996). These publications indicate that particles larger than 10 $\mu$m in size can shield microorganisms from disinfection by UV light.

### CHLORINE DISINFECTION PERFORMANCE

Chlorine, like UV, is effective for the disinfection of bacteria, both in free and combined form. Like UV, chlorine disinfection is impacted by the existence of particle-associated organisms. Also like UV disinfection, chlorine disinfection performance is impacted by the chemical nature of the water. Of substantial note, however, is that the chemical impact of wastewater quality to UV is directly compensated for during UV design and operation through the incorporation of ultraviolet light transmittance (UVT) data, whereas there is no current monitoring or method to adjust chlorine doses based on the chemical nature of wastewater, since the basis for compliance is a total chlorine residual. Dietrich et al. (2003) presented definitive dose/response data showing two phase disinfection kinetics with rapid kill of total coliform (likely non-particle associated) at low *Ct* values followed by a dramatically less effective kill of the remaining particle-associated organisms (a classic "tailing" effect). Further, Dietrich et al. (2003) presented evidence that chlorine disinfection is not accurately measured by *Ct*, as higher dose/shorter contact time *Ct* values provide better disinfection than lower dose/higher contact time *Ct* values. Sung (1974) studied the impact of a range of wastewater organics on chlorine disinfection potential and reported that most of the organics studied (studied compounds include carbohydrates, proteins, carboxylic acids, tannins, lignins, detergents, and other compounds) "react with chlorine to form chloro-organic compounds," titrating as chlorine residual "yet were found to have little or no bacteriocidal (bactericidal) potential." Essentially, standard *Ct* values, relying on the determination of a total chlorine residual without an understanding of what species make up the chlorine residual, do not result in predictable chlorine disinfection performance.

For disinfection of pathogens, chlorine performance is equally, if not more, variable. Free chlorine is a rapid and effective viral disinfectant in wastewater, as indicated by Figure 1, with 5-log reduction of MS2 at a *Ct* of less than 60 mg-min/L (well below the *Ct* required by the State of California for reclaimed water, but above some standards set by the State of Florida). The use of MS2 as a conservative surrogate for poliovirus was proven in Cooper et al. (2000). Note the tested water in Figure 1 was a high quality wastewater, nitrified and filtered with a chlorine demand of 1.5 mg/L. The existence of ammonia in moderate concentrations and/or the presence of a high level of organics will result in a combined residual with measurably worse disinfection potential, as shown below.

**Figure 1.** *Disinfection of MS2 by Free Chlorine (adapted from Cooper et. al. 2000)*




The EPA differentiates between the efficacy of combined chlorine and free chlorine (for drinking water disinfection). The EPA Guidance Manual (USEPA 1999) indicates that a *Ct* of up to 1000 mg-min/L is required to achieve 4-log virus reduction, using chloramines. Recent research (Cooper et al. 2000) substantiates the Surface Water Treatment Rule conclusions, showing minimal viral disinfection by chloraminated wastewater, even though the tested water was microfilter effluent (0.2 $\mu$m pore size) with a chlorine demand less than 1 mg/L (Figure 2 and Figure 3, indicating required *Ct* values of >1500 mg-min/L and from >300 to 1500 mg-min/L for 5-log kills of MS2 and poliovirus, respectively, in some cases well beyond the *Ct* requirements of *any* state). Additional new free chlorine data from this author, not published in Cooper et al. (2000), is shown in Figure 2 to underscore the impact of ammonia on chlorine disinfection performance.

**Figure 2.** *Disinfection of MS2 by Combined Chlorine (adapted from Cooper et. al. 2000, supplemented by new free chlorine disinfection data for comparative purposes)*

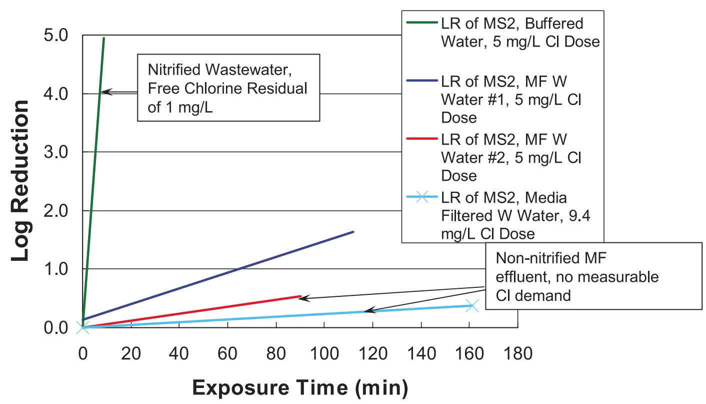
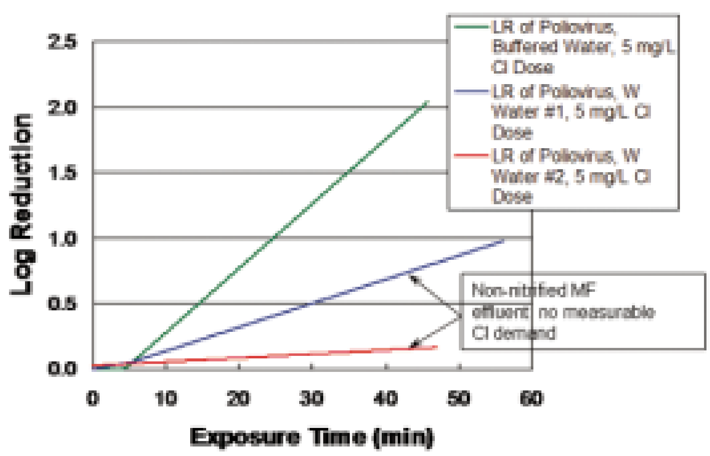



**Figure 3.** *Disinfection of Poliovirus by Combined Chlorine (adapted from Cooper et. al. 2000)*



The use of chlorine for reclaimed water disinfection raises concerns, in light of recent FDEP protozoan treatment goals (FDEP 2003) and the research and publications by Slifko (e.g., Slifko et. al. 2004), which show numerous detections of *Giardia* and *Cryptosporidium* (some viable) in reclaimed water effluents (in most cases with chlorine as the disinfectant).

The USEPA (1999) specifies that drinking water treatment engineers should only anticipate significant *Giardia* kill with free chlorine (3-log kill at a *Ct* of ~50 mg-min/L, depending on temperature and pH), as combined chlorine requires a *Ct* of >1,000 mg-min/L for an equivalent level of treatment.

Regarding *Cryptosporidium* kill, research has shown little to no disinfection by either free or combined chlorination (see USEPA 2006). It should be noted that USEPA 1999 is for drinking water treatment, and not for wastewater, which would be expected to have higher chlorine demand, due to wastewater and organics. As a result, CT values for wastewater will likely be measurably higher for the same disinfection result.

## SUMMARY

The work discussed above, along with findings from other previous research, has resulted in heightened concern about the added health risk associated with the use of chlorine disinfection of reclaimed water when compared to other proven disinfectants, including UV. A WateReuse Foundation sponsored research investigation, titled "Pathogen Inactivation through Wastewater Reclamation," is underway to address this concern.

If the target for reclaimed water disinfection is pathogen reduction, then the technology-specific regulated dose targets must be evaluated as to their relative ability to produce "pathogen-free" water at each treatment location. Only with this understanding can two technologies, such as chlorine and UV, be properly compared to each other. Each process may have different controlling factors, but the end product should generally pose the same degree of risk to the user or consumer. In total, performance, and not solely cost, should be a primary driver in disinfection process selection.

*Comment:* We know that not all pathogens are present at the same concentration throughout the year. The problem is that their appearance is not predictable and our monitoring systems are not adequate to provide a quick enough response. Therefore, a treatment barrier is erected to reduce or inactivate pathogen loads that may occur infrequently. Given the source of recycled water, the California Department of Health Services feels it is prudent to erect multiple barriers to reduce and minimize public exposure to these pathogens.

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