# Disinfection with Chlorine Products

## Some Lessons Learned

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*Chlorine's unique properties have been exploited for water disinfection for roughly 100 years, yet only recently, through comparisons with alternative methods, have we begun to understand the multiple features that make chlorination effective. This presentation deals with three features of chlorine disinfection for pools and spas: rapidity of action, persistence in the water and circulation system, and contributions to biostability of the treated water. Starting with the evidence of microbial risk and its relationship to the water circulation system, the discussion will proceed to a comparison of laboratory and field experiment results for a variety of chlorine and alternative sanitizer systems.*

## Background

In this paper are summaries of three studies that highlight different aspects of disinfection with chlorine: a field study of home pools showing the importance of residuals; a spa study illustrating its rapid action against bather introduced bacteria; and an experimental pool study showing long–term efficacy in use. While these three aspects of chlorine disinfection are not startling to people who have relied on sanitization with chlorine products through the years, they do present a vivid reminder of chlorine's superior ability to clean and disinfect water.

Pool and spa sanitization offers a range of challenges including organic compounds and microbes introduced by the bather and, because they are open to the air, through the actions of wind, rain and top–up water. Because the water is also recirculated, each of these introduced materials must be chemically or physically removed. In addition, pools and spas provide a variety of ecological niches (sand and other filter media, pipes, pool sides and bottom, air jets) all of which provide opportunities for microbial growth.

While not all (or even most) of the microbes which can grow in the pool and spa environment cause disease, many can. Table 1 shows some of the diseases which the Centers for Disease Control and Prevention (CDC) indicate have been transmitted in improperly sanitized pools and spas (Moore *et al.* 1993, Kramer *et al.* 1996, Price and Ahearn 1988, Highsmith and McNamara 1988, Hoadley and Knight 1975, CDC 1982). The list shows a range of diseases and the microorganisms that cause them: viruses, such as those causing Hepatitis A; protozoa causing a wide range of diseases; and bacteria, responsible for the most common diseases contracted from pool and spa use — otitis externa and dermatitis folliculitis.

There are two things about this list that I would especially highlight. First, it shows some of the variety of challenges that the microbial world presents. Besides these pathogens, there are other microbial problems. For example, there are algae of various types which present their own risks to swimmers — slip hazards and, in the worst cases, visibility problems. Second, it points out that hazards come both from other bathers and also from the environment. Both otitis externa (swimmer's ear) and dermatitis folliculitis are common and both are caused by pseudomonas species found in the environment as well as on other bathers who may or may not have any symptoms. Likewise, legionella species, responsible for Legionnaire's disease and for a flu–like disease called Pontiac fever, are found in the environment. In other words, no sick person needs to come near a pool or spa for it to be a source of these diseases. All that needs to happen is for populations of these bacteria to grow up and to be present in the water in sufficient numbers when a susceptible person is in the water or nearby. Spas, with their capacity to aerosolize the water provide a way for even non–swimmers to be infected — if the water is not clean.

These challenges mean, then, that to be effec-

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| Disease | Causative Agent(s) |
|---|---|
| Otitis externa (swimmer's ear) | *Pseudomonas sp.* |
| Dermatitis folliculitis (a rash) | *Pseudomonas sp.* |
| Gastroenteritis (gastrointestinal problems) | Enteroviruses, *Giardia*, *cryptosporidia*, others |
| Hepatitis A | Virus |
| Legionnaire's disease | *Legionella sp.* |
| Amoebic corneal infections (an eye infection) | Acanthamoeba |

**Table 1 – Diseases Transmitted in Pools and Spas**

tive a sanitizer 1) must provide rapid kill to prevent bather–to–bather infections, 2) must be maintained above a minimum level in order to protect against environmental organisms carried into the pool, and 3) must have a wide range of activity to be effective against many types of microorganisms that may cause disease. To this list I would add two requirements for effective long–lasting sanitization. The sanitizer should destroy the microorganism, if possible, to reduce the possibility of the development of resistant organisms. And the sanitizer should work in conjunction with the filtration and circulation system to remove the organic material that provides food and shelter for microorganism growth. These latter abilities contribute to the biostability of the water, making it less likely to promote the growth of microorganisms. In the discussion below, you will see some evidence of chlorine's superior ability to provide all of these functions, helping pool owners to keep the water clean and healthy.

## Case 1 – The Quality of Residential Pool Water

While public pools and spas are subject to regulation and inspection by state and local health departments, no systematic programs exist to test and assure that residential pools are microbiologically safe for their owners. There are no standards for the homeowner — so what should we expect? Suppose we applied public pool numbers to the typical home pool. Would it pass? Can you be sure that if your pool has at least the minimum levels of available chlorine it will be safe for your kids and your grandmother? In 1988–90 we conducted a survey of 126 residential pools across the US that helped answer those questions. All of these pools were tested for bacteria using duplicate Millipore Total Plate Count® samplers (Millipore Publication 1985). Questionnaires were completed by the owners, water samples were collected and analyzed, and for a subset of these pools (20 from the Dallas area) residual sanitizer was also measured. Pool owners were questioned on the sanitizer they were using and recent patterns of pool use and maintenance.

We found that, of the 126, 121 (95%) were using chlorine — either sodium hypochlorite, calcium hypochlorite, a chlorinated isocyanurate, or in one case a chlorine generator. Of the remaining five, one was using a three part non–chlorine system with polyhexamethylene biguanide, PHMB, as primary sanitizer, three were using bromine tablets and one believed he was using chlorine and was in fact adding chlorine, but because of high bromide residuals in the pool had only bromine for sanitization. This is relevant to disinfection since bromine cannot be stabilized to protect it from the sun's ultraviolet rays. Therefore, maintaining the required residual for bromine disinfection outdoors requires special vigilance.

To analyze for bacteria, the Millipore samplers were incubated for two days at 31°C, and the colonies which grew up were counted. A recount after 6 days of incubation was also performed. Because no dilutions were performed on the samples, the range of

| Sanitizer | Chlorine | Other | Total |
|---|---|---|---|
| Number of pools | 121 | 5 | 126 |
| Count = 0 cfu/mL | 25 (21%) | 0 | 25 (20%) |
| 1–10 cfu/mL | 51 (42%) | 1 (20%) | 53 (42%) |
| 11–100 cfu/mL | 27 (22%) | 2 (40%) | 28 (22%) |
| 101–200 cfu/mL | 8 (7%) | 0 | 8 (6%) |
| >200 cfu/mL | 10 (8%) | 2 (40%) | 12 (10%) |

**Table 2 – Bacteria in residential pool survey**

possible results is from less than 1 colony forming unit (cfu) per milliliter to greater than 300 cfu/mL.

Table 2 summarizes the six day counts for the pools. Each result is the average of two samplers from the pool. For comparison with these results, we consider the level most often cited in health codes (U.S. DHHS 1985, APHA 1981): the heterotrophic plate count, sometimes cited as the standard plate count, should not exceed 200 cfu/mL.

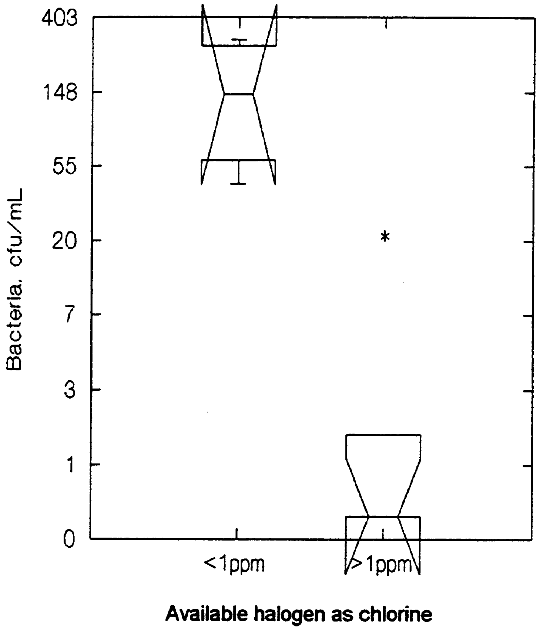
Inspection of Table 2 shows that the great majority of the total (90%) would pass the public health criterion. Sixty–two percent of the pools had 10 or fewer bacteria counted, and 42 of the pools (33%) had counts of 0 or 1. If we consider only the chlorinated pools, the picture improves with only 8% of the pools showing more than 200 cfu/mL. In contrast, the non–chlorine pools tended toward higher counts with 2 of the 5 exceeding the guideline values.

Of course, waiting two days to know whether the water is safe is neither desirable nor practical. For this reason, residential pool owners need to be able to measure a residual sanitizer level quickly and to know that its presence is linked to good water quality. Figure 1 presents the relationship between residual sanitizer and the plate counts determined in a set of 20 outdoor residential pools. In this set, there were four pools with less than 1 ppm of available chlorine (or the equivalent in bromine) which is the minimum recommended level in current NSPI standards.

Figure 1 is an example of a notched box plot, displaying the range of the data and the confidence interval on its median. To read more about this kind of diagram you can check the Wilkinson (1992) reference, but for the purposes of our talk, you only need to recognize that the graph shows that for the pools with less than 1 ppm of available halogen expressed as chlorine, results ranged from 81 to >300 cfu/mL. Of the 16 pools where a residual of 1 ppm or greater was present, the highest count observed was 21 cfu/mL and 15 of the pools had 2 cfu/mL or lower. The graph also shows that the difference between the two sets of pools is statistically significant (because the 95% confidence limits do not overlap). This fact is especially significant and apparent when you recognize that the bacteria counts are plotted as an exponential function in Figure 1.

As a side comment, the Dallas pool set includes three pools where, either intentionally or by mistake, the residual sanitizer was bromine. If the bromine pools are removed from the data set, no pool exceeds 200 cfu/mL. In fact, no pool exceeds 100 cfu/mL. One pool remains in the set of pools with less than 1 ppm residual, and it shows 81 cfu/mL. This illustrates the earlier point about the extra vigilance required to maintain a bromine residual outdoors.

What are the lessons from this study? There are two. Maintaining the proper residual is important for sanitation. And most residential pool owners we surveyed were getting the message and maintaining a residual.



*Data from duplicate determinations for twenty residential pools in the Dallas area. Sanitizer level from chlorine or bromine is expressed as its equivalent in chlorine.*

**Figure 1 – Bacteria vs. Sanitizer Level**

## Case 2 – Bacteria in a spa experiment.

The second study I will describe comes from the very challenging area of spa maintenance and illustrates the importance of rapid kill for effective disinfection. In this study a commercial copper silver ionizer was evaluated following the manufacturer's instructions. The unit was installed on a 300 gallon spa which had previously been drained, cleaned and filled. It was operated until the unit indicated that the water had reached acceptable ion levels. Water samples were taken at that point, and then four adult male employees entered the spa. After 30 minutes they left the spa and additional water samples were taken. Samples were also taken at 15 minutes (during use) and at 24 hours after use.

Bacteriological analyses included total and fecal coliforms and fecal streptococci using the most probable number (MPN) method and total bacterial count by the heterotrophic plate count (HPC) method (APHA 1976–1995). Unacceptable bacteriological quality is indicated by HPC of 200 cfu/mL or higher or by a positive test in any of five 10 mL samples in the MPN tests.

Table 3 presents the results of the microbiologi-

| Cu/Ag Ionizer Alone | Before Use | 15 minutes | 30 minutes | 24 hours |
|---|---|---|---|---|
| Standard Plate Count (SPC) | <1 /mL | >3000 /mL | >3000 /mL | <1 /mL |
| Total and fecal coliform MPN | 0 of 5 pos. | 4 of 5 pos. | 0 of 5 pos. | 0 of 5 pos. |
| Fecal Streptococci MPN | 0 of 5 pos. | 5 of 5 pos. 1 of 5 conf. | 5 of 5 pos. 2 of 5 conf. | 0 of 5 pos. |

**Table 3 – Microbiological Quality of Spa Water Treated with Copper/Silver Ionizer and Used by Four Bathers**

cal testing for the copper silver ionizer in the absence of any chlorine. Initial good quality water quickly rose to show more than 3000 cfu/mL by standard plate count methods when the bathers entered the spa. The samples also showed elevated MPNs for total and fecal coliforms and for fecal streptococci. Both the HPC and the fecal streptococci numbers were still elevated at 30 minutes, though after 24 hours (with continuous running) the numbers were back to pre–bather levels. Copper and silver ionizers eventually kill the bacteria brought into the spa by the bathers, but not while the bathers are in the water. A slow kill rate means the devices, unless supplemented by a quick–acting residual sanitizer in the water, are not going to be effective in preventing bather to bather infections.

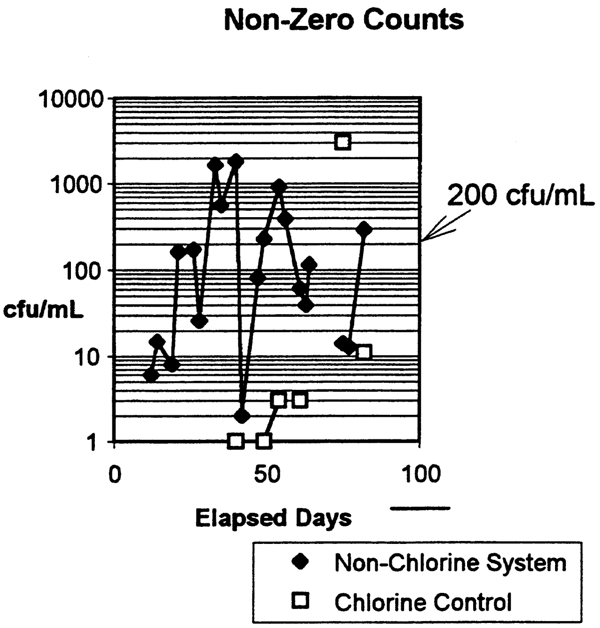
These results are in marked contrast to the results obtained for calcium hypochlorite. In nine trials where initial free chlorine levels were between 3.4 and 4.3 ppm, no SPCs above 200 cfu/mL were observed and no positive MPNs were obtained (Brigano 1980). Clearly calcium hypochlorite is providing rapid kill of the bacteria that the bathers bring into the spa. This helps to explain the good record of chlorine in preventing bather–to–bather infections.

## Case 3 – Long term disinfection in experimental pools

The final case that I will discuss is a long running series of experiments in our trial pools. The pools in these experiments were carefully maintained following label instructions for each test product. They were vacuumed and backwashed weekly. No bathers utilized the pools, but a synthetic batherload, made up of components of perspiration and urine and scaled to represent residential pool use levels, was added five times per week. Algae cultures were added every week, supplementing the natural addition from the environment. Levels of sanitizers and water balance parameters were monitored and samples were taken and plated to obtain bacteria levels (heterotrophic plate count) two or three times per week. The HPC samples were incubated and counted after two days and after 1 week. A difference between the two counts indicates injured or slowly growing bacteria.

The results that I want to discuss here come from a trial of a three part non–chlorine system consisting of PHMB (polyhexamethylene biguanide), a weekly treatment with a quaternary ammonium–based algaecide, and a monthly hydrogen peroxide treatment. Manufacturer's instructions were utilized to determine dosage, and levels of PHMB were maintained within the recommended levels. Starting with a new aboveground pool equipped with a sand filter and a heater to extend the New England season, the pool was operated for 90 days in 1992, was winterized according to manufacturer's instructions and then restarted and operated for 100 days in 1993.

During the first season, very few samples from the PHMB system pool showed bacteria counts above the detection level of 1 cfu/mL after two days of incubation. However, after the longer 1 week incubation period, some counts were observed. Figure 2 presents the non–zero heterotrophic plate counts obtained after 1 week incubation periods. The graph shows that of the 26 readings completed in this period seven were

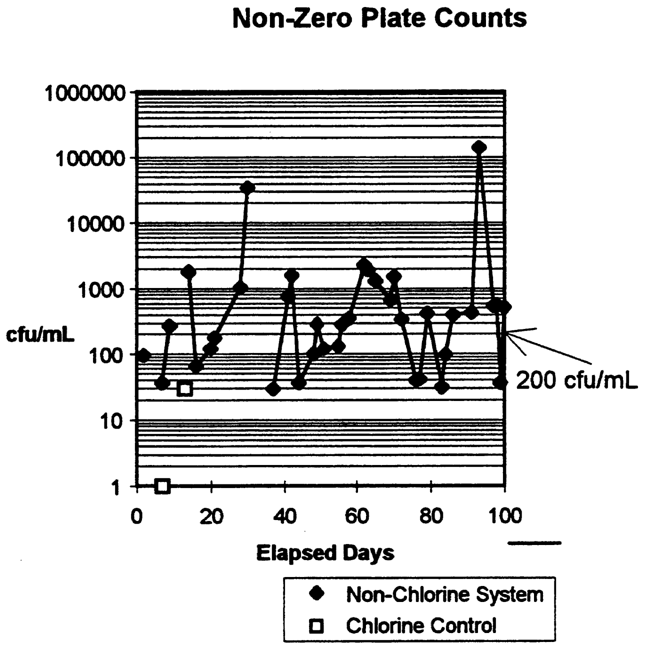


*Non–zero results for bacteria in a PHMB and a calcium hypochlorite pool during their first season of operation. Incubation for 1 week allowed injured or slowly growing bacteria to become visible.*

**Figure 2 – Bacteria in Experimental Pools by HPC, First Season**

above 200 cfu/mL for the non–chlorine system. The differences between the two day and 1 week counts may be an early warning of the development of resistant strains of bacteria in the pool — which continued to look clear and appealing throughout the study.

Figure 2 also displays results for a chlorine control pool, maintained and monitored identically, but using calcium hypochlorite tablets for daily sanitization and a weekly calcium hypochlorite shock of 7.5 ppm available chlorine. Two day and one week counts for the calcium hypochlorite pool were generally in agreement. After 1 week of incubation, only one sample was found at levels above 200 cfu/mL. In fact, for the chlorine control pool 18 readings were 0, and only 2 counts were above 3 cfu/mL — an excellent record.



*Non–zero results for bacteria in a PHMB and a calcium hypochlorite pool during the second season of operation. Counts are for the more rapidly growing bacteria which become visible after only two days' incubation.*

**Figure 3 – Bacteria in Experimental Pools by HPC, Second Season Results**

Aside from some bacterial slime in the skimmers, the PHMB system pool still looked good during the second season. Compared to the first season, however, the second season for the PHMB system pool was characterized by more numerous bacteria. Also, more of the bacteria were fast–growing in the second season, showing up on the plates after only two days' incubation. Figure 3 shows the two day incubation results for the non–chlorine pool. This season, twenty of the readings were above the public health recommended level of 200 cfu/mL despite the proper measured residual sanitizer. During the second year, then, there were persistent levels of bacteria in the PHMB system pool, and even the addition of hydrogen peroxide did little to assure low counts.

During this same summer, 40 samples were taken from the chlorine control pool. Of these, there were two measurements above zero after two days' incubation. A count of 1 and a count of 29 were observed, both well below the 200 cfu/mL standard. However, administrative requirements had forced a change in the pool assigned as chlorine control. So to get a true second season picture for chlorine we need to look to another set of experiments. Test pools in Florida were running on calcium hypochlorite starting in 1991. Taking the period from October 1993 through March of 1995 when test protocols were most similar to those used at the New England site, we have a set of 192 samples, plated and counted at 2 days and at 1 week. Table 4 below summarizes the results of these measurements. Three counts exceeded 200 cfu/mL while 171 samples were 10 or lower, even after the longer incubation period to allow slower growing organisms to appear. Calcium hypochlorite remained active and effective throughout the test period.

In fact, the development of persistent counts has never been observed in our calcium hypochlorite control pools. Resistant strains of bacteria are slow to develop (if they develop at all) in the pools that are treated with chlorine, yet begin to appear in the non–chlorine system after a period of use. One reason for

| Heterotrophic Plate Count (HPC) | Incubation for 2 days | Incubation for 1 week |
|---|---|---|
| Samples | 192 | 192 |
| <1–10 cfu/mL | 187 (97.4%) | 171 (89.1%) |
| 11–100 cfu/mL | 2 (1.0%) | 17 (8.9%) |
| 101–200 cfu/mL | 0 | 1 (0.5%) |
| >200 cfu/mL | 3 (1.6%) | 3 (1.6%) |

**Table 4 – Bacteria, Long term Study at Calcium Hypochlorite Pool**

this difference may be the fact that the PHMB system does not allow for strong oxidation of the organic wastes from bathers and the environment. Organic compounds provide food and shelter for bacteria, and organic carbon levels build in the PHMB pools (Olin research reference). It may also be that more organisms are only injured by the non–chlorine sanitizer and its oxygen–based oxidizer. This could afford a chance for reproduction and the development of resistant generations. For whatever reason, the development of persistent bacterial counts in PHMB pools has been an observation repeated in indoor and outdoor experiments in both New England and Florida test sites.

## Summary: Meeting the needs for adequate disinfection

The outbreak data show that effective disinfection in pools and spas is important and that effectiveness against a range of disease–causing organisms is required. The case studies show us some of the disinfectant features that are important:

- rapid action to prevent infections passed from bather to bather
- long term effectiveness against the daily onslaught of microbes and waste products from bathers and from the environment
- a persistent presence
- and easy measurement — where performing a simple chemical test can reassure bathers about the microbial quality of the water

Chlorine in pool water is ably meeting these requirements whether we talk about residential pools, spas or our long term experimental pools.

## Acknowledgments

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