Evaluation of Swimming Pool Filtration Systems

Amy M. Oswald[1], Que Hales[2], Charles Gerba[1] and Georgetta Seidel[1]
[1] University of Arizona, Department of Soil, Water and Environmental Science, Tucson, Arizona
[2] Pool Chlor, Tucson, Arizona

The widespread use of private pools and spas has initiated a concern over proper filtration devices for microbial contaminants. This is especially important for waterborne protozoan parasites such as Giardia lamblia and Cryptosporidium parvum. Diatomaceous Earth (DE), cartridge and sand filters were evaluated along with a nanofiltration system to compare for their ability to remove viruses, bacteria and protozoan parasites. Four different organisms were used in this study to represent the various sizes of waterborne microorganisms that may possibly be shed by infected bathers. Nanofiltration removed MS-2 and E. coli by >99.9%. The DE filter had the next highest removal capabilities as MS-2, E. coli, Cryptosporidium and Giardia were reduced by 59%, 58%, 85% and 95%, respectively. The sand and cartridge filters had the lowest removal capabilities, but in general had an increase in reduction with the increase in microbial size.

Proceedings of the 4th Annual Chemistry Symposium
National Spa and Pool Institute - November 1999
Pages 18-23

Introduction

Currently the concern over microbiological contaminants in pools and spas has increased due to outbreaks (Barwick *et al.* 2000). Numerous disease outbreaks have been reported from pools caused by agents such as *Cryptosporidium* (MacKenzie *et al.* 1995; Hellard *et al.* 2000), *Giardia* (Porter *et al.* 1988), enteroviruses (Keswick *et al.* 1981), and *E. coli* O157:H7 (Friedman *et al.* 1999). A variety of microorganisms, including bacteria, viruses and protozoa can cause an array of enteric diseases that differ in severity. For example, giardiasis is caused by the infection of the small intestine by the protozoan parasite, *Giardia lamblia*. This disease is characterized by diarrhea, malabsorption and growth failure in children (Farthing 1994). Infected bathers shedding these organisms can contaminate pools and spas. Ultimately other swimmers may be infected followed by disease. Table 1 lists the densities of various microorganisms shed by humans.

There are multiple reasons associated with microbial outbreaks in pools and spas. One explanation is the insufficient removal of microorganisms by pool and spa filtration systems. This is particularly important with protozoan parasites such as *Giardia* and *Cryptosporidium*, which are very resistant to inactivation by chlorine (Venczel *et al.*, 1997). The investigation of these systems is important in the prevention of disease outbreaks.

Filter Capability Study

The purpose of this study was to determine the

Microorganism	Density (g)	Reference
Coliforms	3.78×10^7 cfu	Feachem *et al.*, 1983
Fecal coliforms	2.27×10^6 cfu	Feachem *et al.*, 1983
Giardia lamblia	10^5 cysts	Maier *et al.*, 2000
Cryptosporidium parvum	10^5-10^6 oocysts	Maier *et al.*, 2000

Table 1 - Density of microorganisms per gram of feces

ability of cartridge, diatomaceous earth (DE), sand and nanofiltration systems to remove various sized microbial contaminants. The microbes involved in this study may themselves cause enteric disease or may only represent the size characteristics of an actual disease–causing organism. In order to mimic the size of a virus contaminant, the bacteriophage MS–2 was used. Larger than viruses, bacteria were represented by *E. coli*. Finally, the protozoan parasites, *Cryptosporidium parvum* and *Giardia lamblia* were studied based on their abilities to cause enteric illness and as representation of the largest size faction for removal in this study.

Recent manufacturer's claims for removal capabilities of filter media include, removal of 15–20 µm particles for sand filters, 10–12 µm particles for cartridge filters, 5µm particles for DE filters and removal to nm–sized particles for nanofilters (Dreisbach, 1999). Other claims, published by service technicians suggest that these capabilities are unrealistic and actual values are more like 60 µm particles for sand filters, 20 µm particles for cartridge and 7 µm particles for DE filters (Tamminen, 1995). The variation in these claims has prompted this investigation to determine the actual ability of these systems to remove microbial contaminants.

Other preventative measures, such as the maintenance of proper water chemistry, are activities that private owners may or may not sustain routinely. Therefore, pool owners should understand that the proper maintenance and operation of their filters could play an important role as a supplement to disinfection. These systems may also serve as the primary barrier to chlorine resistant disease agents, such as *Giardia* and *Cryptosporidium* (Gerba, 1995).

Materials and Methods

Materials

The equipment used in this study includes a 1 HP pump/motor (Sta–Rite Max–E–Glas II), cartridge filter (Sta–Rite System 3 Model PLM150), diatomaceous earth (DE) filter (Sta–Rite System 3 Model S7D75), sand filter (Sta–Rite System 3 Model S7S50) and a two–stage nanofilter (Clean Water Products). Table 2 lists the physical parameters in which the filters were operated during the study.

The tap water used in this study was measured for several physical and chemical parameters before use. The pH of the water was 7.30. Total hardness (TH) and total calcium (TC) readings were 182 mg/L as $CaCO_3$ and 120 mg/L as $CaCO_3$, respectively. The ratio of total hardness to total calcium was 66%. Total alkalinity (TA) was 180 mg/L as $CaCO_3$. Total dissolved solids (TDS) were measured at 210 mg/L. Iron (Fe) and Copper (Cu) readings were 0.05 and 0.02 mg/L, respectively. Free and total chlorine was 0.00 mg/L and cyanuric acid (CYA) readings were 0.00 mg/L.

Methods

The sampling was conducted at Pool Chlor's Tucson Facility. A diagram of the filters and testing setup is shown in Figure 1. Reservoir A was filled with 1500 gallons (5670 L) of tap water. A 10% solution of sodium thiosulfate was added to neutralize any residual chlorine that may have been present in the tap water. This solution was allowed to mix for approximately 10 minutes. At this point, over 2000 mL of neutralized tap water was flushed through the nanofilter system.

After the solution was allowed to mix and the nanofilter was flushed, a chlorine measurement was taken. Once it was determined that there was no residual chlorine present, the test microorganisms were added to Reservoir "A". The microorganisms used in this study included the bacteriophage, MS–2 ATCC strain 15597–B1 (American Type Culture Collection, Rockville, MD), *Escherichia coli* ATCC strain 25922 (American Type Culture Collection, Rockville, MD), *Giardia lamblia* and *Cryptosporidium parvum*. MS–2 was added to represent the 18–100 nm ranges of enteric viruses (Maier, 2000) (i.e. hepatitis A virus, Norwalk virus, etc...) and was added at a concentration of 10^4 plaque–forming units (pfu) per mL. *E. coli*

Filter	Pump Vacuum (in. Hg)	Filter Pressure (psi)	Flowrate (gal/minute)
Cartridge	7.25	11.9	83.9
DE	8.38	11.1	83.5
Sand	8.50	13.8	77.8
Nanofilter:			
Product	NA	NA	0.77
Reject	NA	NA	3.08

NA = not applicable

Table 2 – Filter Parameters

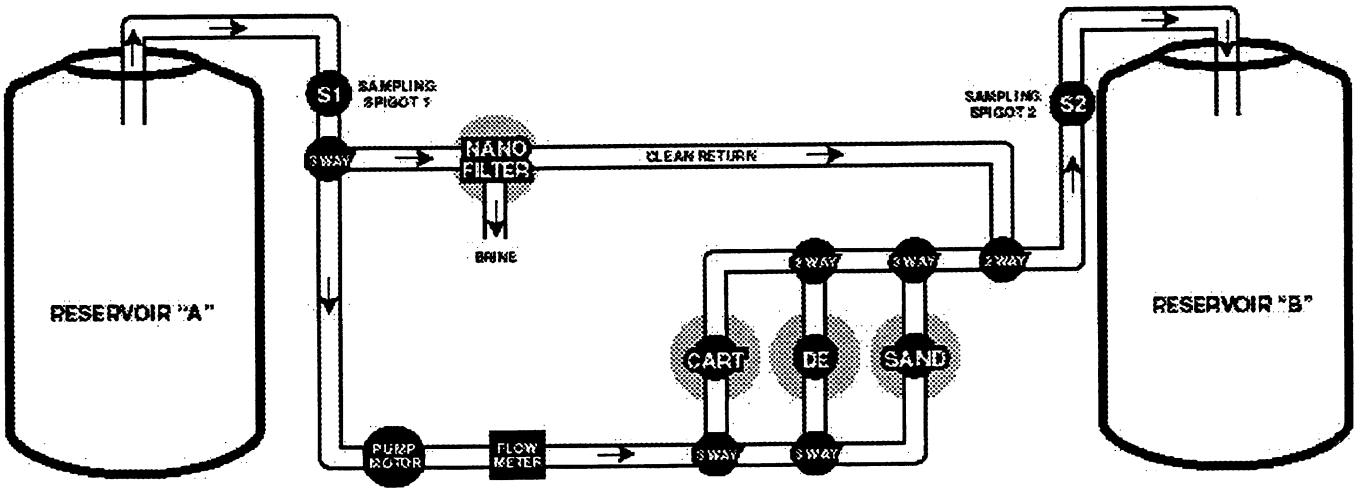
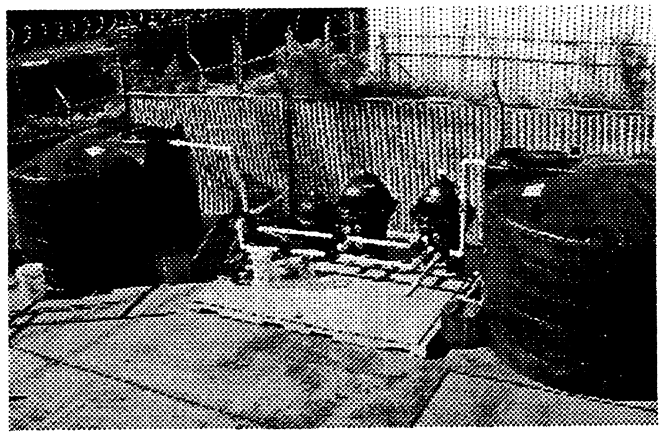


Figure 1 – Diagram of Experimental Setup



was added to represent the 0.3–5 μm range (Maier, 2000) at a concentration of 10^5 colony–forming units (cfu) per mL. *Cryptosporidium parvum* was added to represent the size range of 3–7 μm (Wallis, 1994) and was added at a concentration of 10^5 oocysts per mL. *Giardia lamblia* was added to represent the 9–12 μm size range (Wallis, 1994) and was added at a concentration of 10^5 cysts per mL. Once the organisms were added to Reservoir "A", the solution was allowed to mix for ten minutes.

Water was drawn from Reservoir "A" through each of the four filters individually and one–liter samples were taken from the influent and effluent of each filter at the two marked sampling spigots (see Figure 1). Effluent water was accumulated in Reservoir "B". After collection, all samples were placed in an ice–packed cooler and transported to the University of Arizona for laboratory analyses. Each sample was analyzed for pH, temperature (°C), Cl_2, MS–2, and *E. coli*. *Cryptosporidium* and *Giardia* were only sampled in the influent and effluent of the sand, DE and cartridge filters, as the nanofiltration system was not available.

Samples were processed for *E. coli* and MS–2 within 6 h of sample collection. Parasite samples were eluted and preserved within 48 h. *E. coli* was detected by a membrane filtration method on mFC media (Difco Laboratories, Detroit, MI) as described in *Standard Methods* (1995). MS–2 was detected by a double–layer method described by Adams (1959). The host strain used in the assay was *Escherichia coli*, ATTC strain 15597 (American Type Culture Collection, Rockville, MD).

Giardia cysts and *Cryptosporidium* oocysts were detected simultaneously by an indirect immunoflourescence method described in *Standard Methods* (1995). The samples were labeled using fluorescent antibodies (Hydroflour™ Combo Kit, Strategic Diagnostics, Inc., Newark, DE) specific for both *Giardia* cysts and *Cryptosporidium* oocysts. Cysts and oocysts were identified on the basis of shape, size and immunofluorescence (APHA, 1995). Temperature was taken at each location during sample collection using a mercury thermometer. The pH and chlorine measurements of each water sample were determined at sample collection using Aqua Chek Gold 5 pH and chlorine indicator strips (Environmental Test Systems, Elkhart, ID).

Filter	pH	Temperature (°C)	Free chlorine (mg/L)
Sand	7.65	25.3	0.00
Cartridge	7.60	25.4	0.00
DE	7.73	25.6	0.00
Nanofilter	7.50	26.0	0.00

Table 3 – Physical and chemical parameters monitored during the study

Pool Filter	Microorganism	% Removal
Sand Filter	MS–2	9
	E. coli	17
	Cryptosporidium	33
	Giardia	38
Cartridge Filter	MS–2	23
	E. coli	21
	Cryptosporidium	34
	Giardia	48
DE Filter	MS–2	59
	E. coli	58
	Cryptosporidium	85
	Giardia	95
Nanofilter	MS–2	>99.99
	E. coli	>99.9
	Cryptosporidium	ND
	Giardia	ND

ND=not determined

Table 4 – Percent of MS–2, *E. coli*, *Cryptosporidium* and *Giardia* removed by Sand, Cartridge, DE and Nanofiltration

Results

This study was conducted in November of 1999. MS–2 and *E. coli* were seeded twice during the study and the results for each experiment were averaged. *Giardia* and *Cryptosporidium* were studied only once. The results of the physical and chemical parameters taken during the study are listed in Table 3. The influent and effluent values were averaged for each filter type.

The influent and effluent concentrations for each organism were used to determine the percent removal for each filter (Table 4). This value was calculated using the following formula:

Percent removal = $(N_{effluent}/N_{influent}) \times 100–100$

$N_{influent}$= number of microorganisms within the influent water

$N_{effluent}$= number of microorganisms in the effluent water

Discussion and Conclusions

The results of this study show that the nanofiltration system provides the highest removal capability based on microorganism size. This filter provided >99.9% removal of *E. coli* and MS–2. Even though *Giardia* and *Cryptosporidium* were not tested by the nanofilter in this study, these organisms would also be expected to be successfully removed, as they are comparably much larger in size. Unfortunately, this unit may not be the most practical filtration system for a private pool or spa owner to use. Nanofilters cost more than the other systems and have flowrates too low to meet current Pima County Health Department requirements for pool water turnover. These systems also clog easily when micron–sized particles are filtered. These issues take precedence over the actual ability of the system to remove microorganisms, and so a more practical filtration system must be identified. Other alternatives have been suggested, including the use of a nanofilter in conjunction with another filter system to optimize microbial removal, specifically for *Giardia* and *Cryptosporidium* (Stauffer 1999).

The DE filter had the next highest removal capabilities for the four organisms studied. This system was able to remove *Giardia* and *Cryptosporidium* by 95% and 85%, respectively. MS–2 and *E. coli* were both removed by about 60% when flushed through this filter. This system may be more practical for a homeowner to use. There are some maintenance issues concerning the relatively fast clogging of the filter that may require additional attention. Backwashing of the filter as it becomes dirty or clogged is feasible, yet the waste may need further separation before being discharged (Dreisbach 1999). In

addition, the filtration is documented at 2 gpm per square foot, which is between the values for sand and cartridge filters. The DE is therefore a practical filtration system that along with proper routine chemistry and continual maintenance will provide efficient removal of microbial contaminants.

The cartridge and sand filter results showed the lowest removal capability for the four microbial contaminants. MS–2, *E. coli, Cryptosporidium* and *Giardia* had only slightly higher removal rates in the cartridge filter, 23%, 21%, 34% and 48% respectively, as compared to the sand filter, which had 9%, 17%, 33% and 38% removal, respectively. According to Dreisbach (1999), the cartridge filter may clog more easily than the sand, but the filtration is much lower at 1 gpm per square foot of filtration surface area compared to 15 gpm for sand. The benefits of these filters over the DE and nanofiltration systems include longer overall filtration time for sand and no water loss during maintenance with the cartridge. Although these factors may be important for homeowners, mechanically speaking, the risk of microbial contamination and disease should be a priority when choosing a filter system. Based on the results in this study, the recommendation would be a combination of the nanofilter with another filter system or the DE filter with the knowledge and understanding of the importance for frequent, proper maintenance.

Acknowledgments

Thanks to Jaime Naranjo and his laboratory for the donation of MS–2 and *E. coli* 25922, use of their equipment and expert advisement.

References

Adams, M.H. (1959). *Bacteriophages*. Wiley Interscience Publisher, Inc., New York.

Barwick, R.S., Levy, D.A., Craun, G.F., Beach, M.J., and Calderon, R.L. (2000). "Surveillance for waterborne–disease outbreaks—United States, 1997–1998." *Mor Mortal Wkly Rep CDC Surveill Summ 2000* **49**: 1–21.

Dreisbach, T. (1999). "Media and size key to residential filters." *Pool & Spa News*. p 33.

Farthing, M.J.G. (1994). "Giardiasis as a Disease." In: Thompson, R.C.A., Reynoldson, J.A., and Lymbery, A.J. (eds.) Giardia: *From Molecules to Disease*, University Press, Cambridge, pp.15–37.

Feachem, R.G., Bradley, D.J., Garelick, H. and D.D. Mara. (1983). *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management.* John Wiley & Sons, New York. pp. 349–356.

Friedman, M.S., Roels, T., Koehler, J.E., Feldman, L., Bibb, W.F., and Blake, P. (1999). "Escherichia coli O157:H7 outbreak associated with an improperly chlorinated swimming pool." *Clin Infect Dis* **29**: 298–303.

Gerba, C.P. (1995). "Outbreaks Caused by *Giardia* and *Cryptosporidium* Associated with Swimming Pools." *JSPSI* **1**: 9–18.

Hellard, M.E., Sinclair, M.I., Fairley, C.K., Andrews, R.M., Bailey, M., Black, J., Dharmage, S.C., and Kirk, M.D. (2000). "An outbreak of cryptosporidiosis in an urban swimming pool: why are such outbreaks difficult to detect?" *Aust NZJ Public Health* **24**:272–275.

Keswick, B.H., Gerba, C.P., and Goyal, S.M.(1981). "Occurrence of enteroviruses in community swimming pools." *Am J Public Health* **71**: 1026–30.

MacKenzie, W.R., Kazmierczak, J.J., and Davis, J.P. (1995). "An outbreak of cryptosporidiosis associated with a resort swimming pool." *Epidemiol Infect* **115**: 545–53.

Maier, R.M., Pepper, I.L., and Gerba, C.P. (2000). *Environmental Microbiology*, Academic Press, San Diego, pp 7–41.

Porter, J.D., Ragazzoni, H.P., Buchanon, J.D., Waskin, H.A., Juranek, D.D., and Parkin, W.E. (1988). "Giardia transmission in a swimming pool." *Am J Public Health* **78**: 659–62.

Standard Methods for the Examination of Water and Wastewater (1995). 19th edn, American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA.

Stauffer, J. "Common pool parasite not problem here – yet." *The Arizona Daily Star,* Monday August 2, 1999, pp.1B, 3B.

Tamminen, Terry. (1995). *The Professional Pool Maintenance Manual.* McGraw–Hill, New York, NY, p.126.

Venczel, L.V., Arrowood, M., Hurd, M., and Sobsey, M.D. (1997). "Inactivation of Cryptosporidium parvum oocysts and Clostridium perfringens spores by a mixed–oxidant disinfectant and by free chlorine." *Appl. Environ. Microbiol.* **63**: 1598–1601.

Wallis, P.M. (1994). "Abiotic Transmission–Is Water Really Significant?" In: Thompson, R.C.A., Reynoldson, J.A., and Lymbery, A.J. (eds.) Giardia: From Molecules to Disease, University Press, Cambridge, pp.99–122.