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Removing *Cryptosporidium*-size microspheres with polyaluminium $FeCl_3$

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ABSTRACT: *Cryptosporidium* is a genus of protozoa that infects swimming pools causing diarrhoea and other illnesses. In this study, the removal of *Cryptosporidium*-size microspheres from a 10 000 l swimming pool was evaluated under varying conditions to provide a reliable and efficient water treatment technique. The baseline condition without coagulation (widely practised in swimming pools today) showed that treating a pool with microspheres at a density of 4000 microspheres per litre through a 33 cm diameter sand filter at 30 m/h flow rate removes 25% of *Cryptosporidium*-size microspheres. The filtration followed by polyaluminium $FeCl_3$ (PAFC) coagulation results in 99% microsphere removal over the 168 h experimental period with filter backwashing every 48 h. Additionally, the impact of the flow rate and filter cross-sectional area was also examined.

KEYWORDS: cryptosporidiosis, swimming pool, recreational water treatment, public health

INTRODUCTION

Cryptosporidiosis is a diarrhoeal illness caused by the infection of the gastrointestinal tract by the protozoan parasite *Cryptosporidium* spp., which can last for days or up to 2–3 weeks[1]. Multiple sources have indicated that infants, young children, pregnant women, and elderly people are more susceptible[2]. *Cryptosporidium* has caused large waterborne disease (cryptosporidiosis) outbreaks and emerged as a parasite of major public health concern in the US, the UK, and Australia[3]. In 1988, 60 cases of cryptosporidiosis occurred in Los Angeles County, USA[4]. In 1990, an outbreak of cryptosporidiosis occurred in British Columbia, Canada[5]. In 2005, more than 4000 swimmers were infected in New York, nearly 2000 more in Utah in the summer of 2007, and at least 378 others in the Dallas area in the summer of 2008[4]. All these outbreaks call for a reliable and efficient swimming pool water treatment technique in response to the public health concerns.

Cryptosporidium spp. are unicellular parasites that infect human epithelial cells of the small intestine, with diameter of 4–6 μm, commonly found in lakes and rivers. *Cryptosporidium* oocysts are environmentally persistent and very resistant to many disinfectants, including chlorine, which is the major barrier to infectious disease transmission that has been used for the past several decades in swimming pool water treatment[6]. Typical swimming pools require at least 1 mg/l (ppm) free residual chlorine. This free chlorine concentration enables 99.9% of *Cryptosporidium* to become inactive for over 11 days[6]. Amburgey reported the sand filter with a thin layer of perlite media on top could remove 98% of *Cryptosporidium*-size microspheres at a filtration rate of 49 m/h from the pool, which was one of the few studies associated with removal of *Cryptosporidium* from the swimming pools, and could help reduce outbreaks of cryptosporidiosis[7]. However, adding perlite on top of the filter might increase head loss and require to add new media after each filter backwash.

Conventional water treatment with coagulation and filtration to remove *Cryptosporidium* from drinking water has been reported[8]. However, coagulation is not typically conducted in swimming pools. Furthermore, swimming pool water treatment is different from that of drinking water. Filters

are operated in drinking water treatment using four to five times lower filtration rate than at swimming pool facilities (5–10 m/h rather than 20–50 m/h), providing a higher probability of particles colliding and adhering to the filter media. Besides, continuous water circulation in a pool, as well as the continuous organic compounds and microorganisms loading by bathers lead to more complex conditions[4].

This study evaluated the high-rate filtration followed by coagulation and discussed main infection parameters including the infection of coagulation concentration versus *Cryptosporidium*-size microspheres concentration as well as filter cross-sectional area versus flow rate. The performances of the representative operation (without coagulation) in real-world swimming pools and the novel operational procedure for pools under the swimming pool condition were compared to produce reliable results applicable to real-world swimming pools. Swimming pool condition refers to water that circulates continuously through the filter with high filtration rate relative to drinking water treatment; organic compounds and contaminants continuously circulate in the pool, and cannot be efficiently removed; and typical pH is controlled in the range of 7.2–7.8[4].

MATERIALS AND METHODS

A 10 000 l swimming pool was built with filtration system and chemical control system. Pool water can be pumped through the filter (Fig. 1). The sand filter was made from transparent polyvinyl chloride (PVC) pipe. The PAFC solution and microspheres were fed into the pipe right in front of the circulation pump for a rapid coagulant mixing. PAFC is a combined coagulant of polyaluminium chloride (PAC) and polymerization $FeCl_3$ with stoichiometric formula $[Al_2(OH)_nCl_{6-n}]_m \cdot [Fe_2(OH)_NCl_{6-N}]_M$. PAFC coagulant solution was made by diluting PAFC with deionized water in a ratio 1/15 (w/w). The simulated swimming pool water was applied in all experiments. A volume of 10 000 l of local tap water was supplemented with $NaHSO_4$, $CaCl_2$, and $NaHCO_3$ to adjust to pool water chemical characteristics: pH = 7.4, alkalinity = 100 mg/l, hardness = 200 mg/l, free chlorine = 1 mg/l.

Experiments were conducted to determine the potential impact of filter media cross-sectional area and flow rate on microsphere removal using the sand filter. Flow rate and corresponded filter diameter is shown in Table 1. Flow rate varied with the filter cross-sectional area, since the turnover time should be 4 h for the pool. Filtration rate between, 20–30 m/h was medium-rate and 30–50 m/h was high-rate filter operation for the pool.

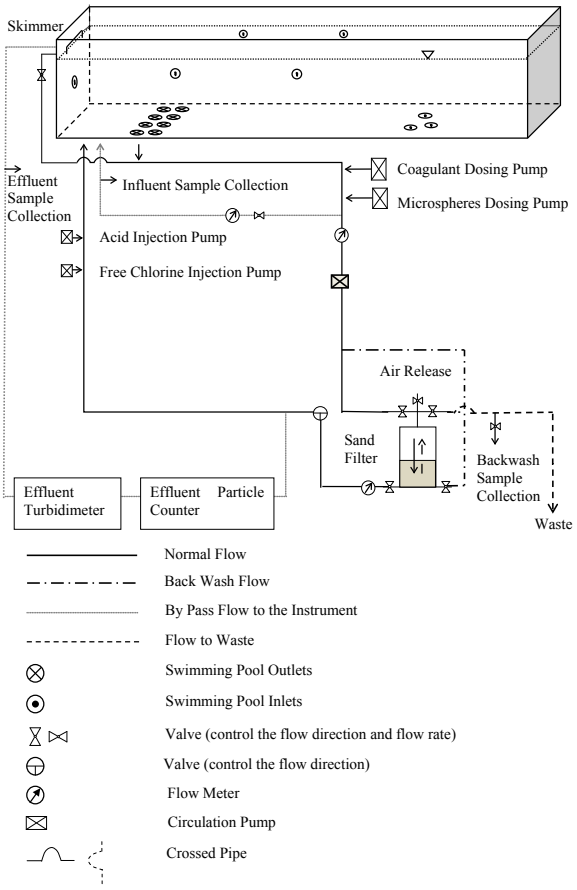

Fig. 1 Swimming pool set-up, 10 000 l.

Table 1 Experimental parameters design based on 4 h turnover.

	Exp 1	Exp 2	Exp 3	Exp 4
Flow rate ($m^3/m^2/h$)	20	30	40	50
Filter cross-section (m^2)	0.125	0.085	0.071	0.049
Filter diameter (cm)	40	33	30	25

Coagulant dose may impact the overall removal. A constant sand filter cross-sectional area (33 cm diameter) and flow rate (30 m/h) was applied in all experiments. Seeding of the coagulant and microspheres simultaneously and continuously was conducted. The experiment was performed in 48 h (12 turnovers) and samples were collected every 4 h.

Paired experiments with and without filter backwash were conducted over seven days (168 h) in order to test the impact of backwash on system

performance and to evaluate the long time system performance. Experiments were also performed with addition of coagulant. Backwash was conducted every 48 h and samples were collected at every turnover.

The use of polystyrene microspheres as an oocyst surrogate has been done by multiple researchers and was used in this study[9]. Microspheres with diameter of 4.5 μm were used as the surrogate since microspheres are virtually identical to *Cryptosporidium* oocysts in size, shape, density, and surface charge in pool water. Microsphere samples were mixed by vortexing and hand shaking for at least 2 min each before analysing. Samples were passed through 3.0 μm pore size polycarbonate filters. Each polycarbonate filter was mounted on a glass microscope slide with a polyvinyl alcohol-DABCO solution, covered with a glass cover slip, and microspheres were counted under an epifluorescence microscope[10]. For ease of counting and to obtain statistically valid data, microscope slides needed to contain between 10 and 150 microspheres. Removal efficiency was calculated by comparing the concentrations between the influent and the effluent samples.

A control experiment was conducted without filter media to test if there were microsphere losses in the system. The average 1% removal rate (approximately zero) was obtained and a virtually insignificant system loss was demonstrated. *Cryptosporidium*-size microspheres removed by the 30 cm depth sand filter at 30 m/h without coagulation was conducted for 24 h as another control experiment. Duplicate experiments were conducted, while triplicate samples in each experiment were taken. The swimming pool was rinsed, filled, and drained with tap water at least three times between experiments to limit the amount of cross-contamination between experiments. Fresh sand was used for each experiment. Sand filter was backwashed with simulated pool water for 5 min to ensure the sand was clean and sand grains restratified (fine grains on top and coarse grains on bottom).

RESULTS

As indicated before, filter media cross-sectional area and flow rate should be adjusted in different direction to maintain a 4-h pool turnover, thus an increase in the flow rate would lead to a decreased cross-sectional area, provided that the turnover is unchanged. Microsphere removals under four different experimental conditions (different sand cross-sectional areas and flow rates) were evaluated

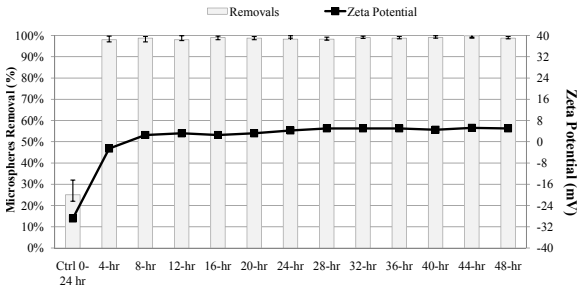

Fig. 2 Microsphere removals under different experimental conditions.

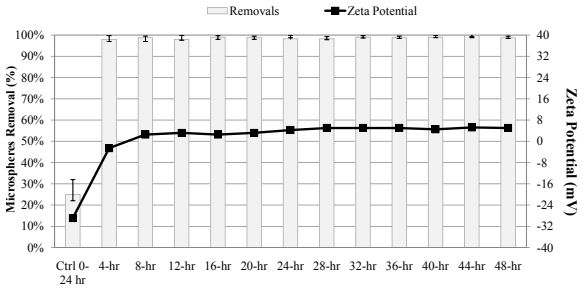

Fig. 3 *Cryptosporidium*-size microsphere removals and ζ-potential variation, 0–48 h, 33 cm diameter sand, flow rate 30 m/h.

(Fig. 2). Approximate 99% of microspheres were removed by 40-cm diameter filter at 20 m/h and 33-cm diameter filter at 30 m/h. Microsphere removals decreased with higher flow rate and smaller filter cross-sectional area. Removals were significantly decreased ($< 90\%$) when the flow rate was 30 m/h (or higher) and the filter diameter was 33 cm (or less).

Percent removal of *Cryptosporidium*-size microsphere and ζ-potential of samples with/without coagulation in 48 h are shown in Fig. 3. Control experiment without coagulant, simulation of today pool water treatment, only achieved 22% to 32% microsphere removals through 33-cm diameter sand filter at 30 m/h. However, the removal efficiency from 97% to 99.9% was achieved by continuous inputs of coagulant at the same operation condition as the control. Results indicated PAFC should be fed continuously to maximize the removal of *Cryptosporidium*-size microspheres from the pool. The ζ-potential was -29 mV for the control without coagulation and increased with the addition of the coagulant. The rest of ζ-potentials of the samples were between -2.6 and 5.3 mV, which was in the range of -10 mV and $+10$ mV, the favourable condition for particle removal[11].

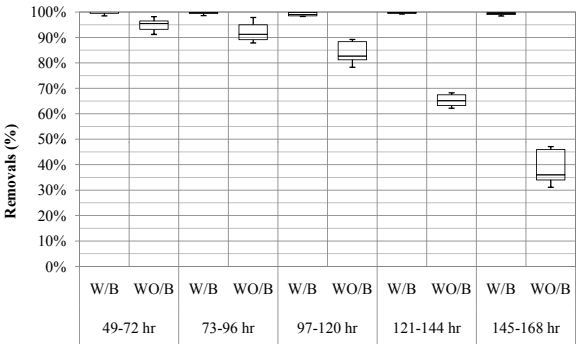

Fig. 4 Microsphere removals with coagulant under conditions with backwash (W/B) and without backwash (WO/B), 48–168 h, 33 cm diameter sand, and 30 m/h flow rate.

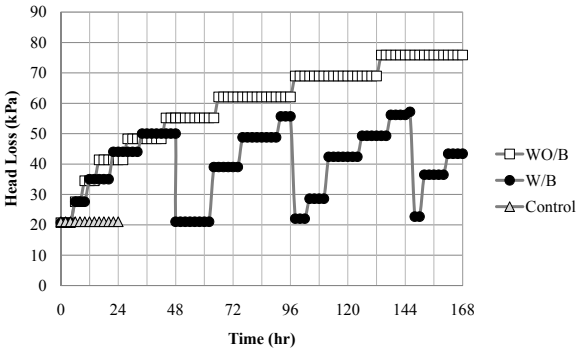

Fig. 5 Head loss variation over time, 0–168 h, (W/B: with backwash and coagulation, WO/B: without backwash but with coagulation, control: without coagulation), 33 cm diameter sand, and 30 m/h flow rate.

Fig. 4 compares removals with/without filter backwash every 48 h. Results showed backwash filter every 48 h achieved stable microsphere removals (97–99%) in 168 h (7 days). However, microsphere removals dropped over time without backwash. Head loss variations are shown in Fig. 5. For experiment without backwash, the head loss increased from 20–76 kPa in 168 h. For experiment with backwash, the head loss fluctuated in 168 h, which rose over time and dropped after backwash. The peaks went up as much as 57 kPa from the baseline pressure of approximately 20 kPa at the bottom of the filter. Results showed removals decreased with the rising head loss, which indicated the larger the head loss was, the lower the removal was under the experimental condition.

Effluent turbidity variation over 168 h is shown in Fig. 6. Control experiment barely removed turbidity as seen in Fig. 6. The effluent turbidity

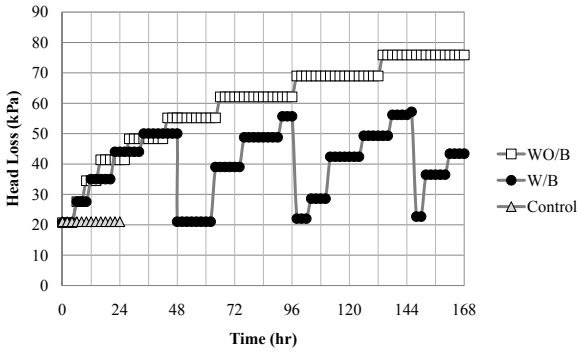

Fig. 6 Effluent turbidity variation over time, 0–168 h, 33 cm diameter sand, and 30 m/h flow rate.

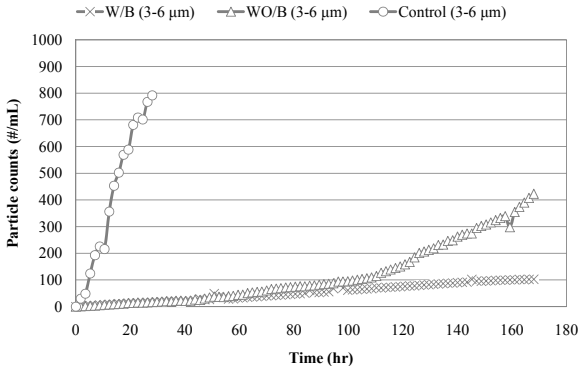

Fig. 7 Effluent particles (3–6 μm) variation over time, 0–168 h, 33 cm diameter sand, and 30 m/h flow rate.

decreased from 2.2 to 1.3 NTU in 7 h and stable at 1.3 NTU. However, much lower effluent turbidity was observed with an addition of PAFC per turnover.

Effluent particle count variations are shown in Fig. 7. The 3–6 μm particle counts went up over time since 4.5 μm microspheres were continuously added. There were many more 3–6 μm particles for the control, comparing the experiments with coagulation because most of the particles were accumulating in the pool. Effluent particle count profiles for experiment with coagulation and backwash were nearly a straight line, and there were three peaks after backwash just similar to the turbidity variation profile. The increased 3–6 μm particle counts showed decreased microsphere removals. Particle counts between 7 and 20 μm were less than 20 microspheres/ml (#/ml) and did not significantly change during the three experiments. The results imply that the particle counters were more sensitive to changes in pool water system compared with turbidities.

DISCUSSION

Comparing with today's pool treatment, simulated by control experiment, only 22% to 32% of microspheres were removed, 97–99% (or even 99.9%) of *Cryptosporidium*-size microspheres were removed through high-rate filtration (30 m/h) and continuous feeding PAFC into the pool with backwashing filter every other day. The enhanced performance was due to the suspension being destabilized by PAFC prior to pool water passing through the filter. The removals of *Cryptosporidium* have been reported to be dependent on the *Cryptosporidium* oocyst concentration in the source water and corresponding coagulant dosage[12].

In terms of microsphere removals decreasing with increased flow rate and decreased filter cross-sectional area, the reasons included: (1) larger surface area tended to capture more particles and the amount of increasing media led to greater removals; (2) the lower flow rate could lead to the higher removals due to less shearing actions within the filter pores, which decreased the transport of particle matters through the filter bed. Proper flow rate and filter cross-sectional area with adequate coagulation in a given turnover time should therefore be discussed for pools.

Head loss increased during experiment, which was due to the particles were entrapped and deposited on the surface and interstices of the filter media. Thus pore spaces of filter were reduced and filter resistance increased. Thus regular backwashing should be conducted to deal with filter head loss increased and microsphere removals declined over time. Turbidity peaks after filter backwashes and return to normal in a short time.

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REFERENCES

1. Mead JR (2002) Cryptosporidiosis and the challenges of chemotherapy. *Drug Resist Updates* **5**, 47–57.
2. Hoxie NJ, Davis JP, Vergeront JM, Nashold RD, Blair KA (1997) Cryptosporidiosis-associated mortality following a massive waterborne outbreak in Milwaukee, Wisconsin. *Am J Publ Health* **87**, 2032–5.
3. Lisle JT, Rose JB (1995) *Cryptosporidium* contamination of water in the USA and UK: a mini review. *J Water Supply Res Tech Aqua* **44**, 103–17.
4. Lu P, Yuan T, Feng Q, Xu A, Li J (2013) Review of swimming-associated cryptosporidiosis and *Cryptosporidium* oocysts removals from swimming pools. *Water Qual Res J Can* **48**, 30–9.
5. Bell A, Guasparini R, Meeds D, Mathias RG, Farley JD (1993) A swimming pool-associated outbreak of cryptosporidiosis in British Columbia. *Can J Publ Health* **84**, 334–7.
6. Korich D, Mead J, Madore M, Sinclair N, Sterling C (1990) Effects of ozone, chlorine dioxide, chlorine, and monochloramine on *Cryptosporidium* parvum oocyst viability. *Appl Environ Microbiol* **56**, 1423–8.
7. Amburgey J (2011) Removal of *Cryptosporidium*-sized polystyrene microspheres from swimming pool water with a sand filter with and without added perlite filter media. *J Environ Eng* **137**, 1205–8.
8. Edzwald JK, Kelley MB (1998) Control of *Cryptosporidium*: from reservoirs to clarifiers to filters. *Water Sci Tech* **37**, 1–8.
9. Amburgey JE, Amirtharajah A, Brouckaert BM, Spivey NC (2004) Effect of washwater chemistry and delayed start on filter ripening. *J Am Water Works Assoc* **96(1)**, 97–110.
10. Freer SM (1984) A permanent wet-mount for fluorescent microscopy of surface stained lymphoid cells. *J Immunol Meth* **66**, 187–8.
11. Tseng T, Segal BD, Edwards M (2000) Increasing alkalinity to reduce turbidity. *J Am Water Works Assoc* **92(6)**, 44–54.
12. Betancourt WQ, Rose JB (2004) Drinking water treatment processes for removal of *Cryptosporidium* and *Giardia*. *Vet Parasitol* **126**, 219–34.