Using turbidity and particle counts to monitor *Cryptosporidium* removals by filters

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Abstract Physicochemical removal of protozoan pathogens is receiving increased attention because of the difficulty of chemically inactivating these organisms, particularly *Cryptosporidium parvum*. Most studies that have examined the removal of these and other pathogens by filtration have been conducted under steady-state conditions with optimized pre-treatment. The research on which this paper is based evaluated the removal of *Cryptosporidium* and surrogates at various points in the filter cycle and under non-optimal conditions, at several pilot plants. The focus of this paper is on the relationship between removals of *Cryptosporidium*, and turbidity and particle counts. Under stable or optimal operating conditions all pilot plants produced similar low filter effluent turbidity and particle counts. Average *Cryptosporidium* removal varied among locations, however, by more than two log units. *Cryptosporidium* removal was impaired under all of the non-optimal conditions. Particle and turbidity performance was also worse, but the relationship of these parameters to *Cryptosporidium* removal varied. Particle counts show greater promise than turbidity as a tool to monitor filter performance in real time for possible deterioration in *Cryptosporidium* removal capability.

Keywords *Cryptosporidium*; filtration; non-optimal conditions; particle counts; real time monitoring; turbidity

Introduction

The primary goal of drinking water supply systems is to protect public health by providing water that is free of microbial and chemical contaminants. The emergence of parasitic protozoa such as *Giardia lamblia* and *Cryptosporidium parvum* as etiological agents of waterborne disease has prompted renewed evaluation of the efficacy of water treatment processes, including granular media filtration.

It is well known that filter effluent turbidity and particle counts may vary in the different phases of a typical filter cycle and as a result of operational events. Ripening, breakthrough, hydraulic surges and suboptimal coagulation may all contribute to poorer performance. The results presented in this paper were obtained from a study (Huck *et al*., 2001) designed to establish whether known increases in filter effluent turbidity and particles under the above-mentioned non-optimal conditions also implied elevated *Cryptosporidium* oocyst levels. The data for the Windsor pilot plant were reported by Huck *et al*. (2000) and included in Emelko (2001). Specifically, this paper focuses on the indications of *Cryptosporidium* removal provided by turbidity and particle counts, both of which can be monitored in real time.

Background

Several pilot- and full-scale studies have demonstrated that organism-sized particles and turbidity are approximate indicators of pathogen removal, but not reliable surrogates (e.g. LeChevallier and Norton, 1992; Nieminski and Ongerth, 1995). Although the risk of *Cryptosporidium* passage appeared to increase with increasing filtrate turbidity in several studies (e.g. Hall and Croll, 1996; Nieminski and Ongerth, 1995), Fuller *et al*. (1995) did not observe significant oocyst passage during filter ripening.

Cryptosporidium oocyst removals by filtration at or near optimized stable operating conditions have been investigated in various full-scale studies (e.g. Nieminski and Ongerth, 1995; Baudin and Laîné, 1998) and pilot-scale investigations (e.g. Kelley *et al*., 1995; Patania *et al*., 1995; Fox *et al*., 1998).

Several studies have indicated that oocyst removals decrease by up to approximately 1 log during filter ripening (e.g. Patania *et al*., 1995; Baudin and Laîné, 1998). Two studies have concluded that oocyst removals are comparable during turbidity breakthrough and stable filter operation (Patania *et al*., 1995; Baudin and Laîné, 1998). Patania *et al*. (1995) noted that the filter effluent turbidity had only increased by approximately 0.1 NTU during their evaluation of breakthrough. Results reported earlier from the present study showed a substantial deterioration in performance during breakthrough (Huck *et al*., 1999). Suboptimal coagulation also had a substantial negative impact on oocyst removal (Coffey *et al*., 1999).

Methods

Experimental design

Most of the experiments were conducted at two pilot plants – one located in Ottawa, Canada and the other at the Metropolitan Water District of Southern California's (MWDSC's) treatment plant in La Verne, California. A small number of experiments was also conducted at a similar pilot plant in Windsor, Ontario. The experiments at all locations were designed to document pathogen removal from benchmark systems and were part of a larger study (Huck *et al*., 2001). In the investigations reported in this paper no attempt was made to improve pathogen removal or mitigate adverse conditions.

In addition to stable filter operation, the conditions investigated were suboptimal coagulation, ripening, breakthrough, and hydraulic step. "End-of-run" experiments were performed at MWDSC because it was not possible to actually achieve breakthrough in that pilot plant. Experiments for each of the conditions were conducted at least in triplicate at each location. Only stable operation conditions were investigated in Windsor. Results for the hydraulic step experiments were variable (Huck *et al*., 2001) and are not discussed herein.

Research platforms and experimental approach

All of the pilot plants received water that was low in turbidity and particles (averages in the range of about 5,000 particles/mL (>2 μm) for Ottawa and MWDSC). Major differences between the raw waters at these two locations included temperature (Ottawa's lowest temperature of 1°C was much colder than MWDSC's) and alkalinity – alkalinity at MWDSC was moderate, while that at Ottawa was low. Each pilot plant was operated to mimic as closely as possible the full-scale treatment plant at the same location.

The filters at all pilot plants contained media depths and sizes typical of the utilities' full-scale plants (and typical of many existing treatment plants). The operational mode chosen was conventional treatment with dual-media filtration.

The Ottawa pilot plant used a high coagulant dose (~40 mg/L alum and 2 mg/L activated silica) to achieve both total organic carbon and particle removal. The MWDSC pilot plant (treating Colorado River water) used a low coagulant dose (5 mg/L alum and 1.5 mg/L cationic polymer) for particulate removal only. Chlorine (~2 mg/L) was added at rapid mix as a pre-oxidant at both pilot plants. Because of the higher coagulant dose and lower alkalinity in Ottawa the coagulation pH was lower – about 6, vs. about 8 at MWDSC. The optimized coagulation conditions were selected to meet a 0.1 NTU turbidity goal. In Windsor, which treats a Great Lakes water, coagulation was optimized for particulate removal. For the experiments reported herein, the acidified alum (15% H_2SO_4) dose ranged from 45 to 70 mg/L; 0.05 mg/L of cationic polymer was also added.

The pilot-scale filters in all locations were seeded with jar-coagulated suspensions of formalin-inactivated *Cryptosporidium parvum*. Except for a small number of experiments that are not discussed herein, seeding of microorganisms was done into the filter influent, primarily to minimize significant losses of microorganisms in upstream unit processes. The targeted seeded influent concentration for *Cryptosporidium* was ~10^5 oocysts per litre. Replicate samples (either four or five) were taken from the filter influent and effluent at each location, normally over a one-hour period during which the seed suspension was being added at the filter influent. A single-factor, analysis of variance (ANOVA) test was selected to interpret the data, which were pooled from the replicate experiments at each location.

In this paper the removals of particles are calculated using the plant influent (rather than the filter influent as in the case of the seeded microorganisms) and the filter effluent, because filter influent particle counts were not measured for technical reasons.

Analytical methods

Oocysts were collected by direct vacuum filtration of filter influent or effluent samples and standard immunofluorescent assay (IFA) techniques were followed to stain the samples. The slides were then either analyzed at the University of Waterloo (for samples from Ottawa and Windsor) or shipped (from MWDSC) to a commercial laboratory (CH Diagnostic & Consulting Services, Inc., Loveland, Colorado), for presumptive microscopic analysis. Although recovery experiments were performed, the measured *Cryptosporidium* levels reported in this paper were not adjusted for recovery.

Each particle counting instrument was calibrated (by the manufacturer) and the calibration was verified onsite. The particle counters measured total particles from 2–150 μm, with the data reported as cumulative particles ≥ 2 μm. Turbidity was monitored using online turbidimeters that were calibrated using dilute formazin solutions as specified by the manufacturer. Calibration was checked by comparison with a bench-top turbidimeter. Differential pressure transducers continuously measured headloss at the MWDSC and Ottawa pilot plants.

Results

Stable operation

As reported by Huck *et al.* (2001) *Cryptosporidium* removals under stable operation conditions in Ottawa were about two log units higher than at MWDSC, being about 5.5 and 3.0 log units respectively. The removals in Windsor, although based on more limited testing, were 4.2 logs.

Figure 1 shows *Cryptosporidium* and particle log removal for all three locations. As noted previously, the influent values used in calculating particle log removals are plant influent rather than filter influent. It is evident that in all cases average *Cryptosporidium* log removal was greater than average particle log removal. Thus in a general sense particle log removal may be used as a conservative qualitative indicator of *Cryptosporidium* removal capability. It should be noted however that in cases where influent particle counts are low, particle counts near the method detection limit may be obtained in the filter effluent. This

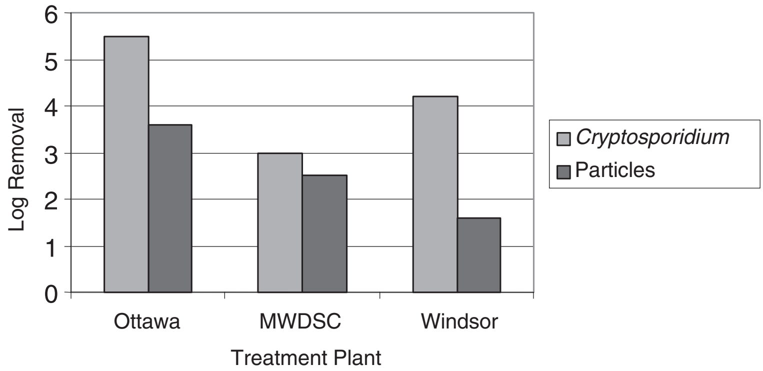

Figure 1 Removals of *Cryptosporidium* and particles under stable operating conditions

could impact the calculated log removals. Figure 1 also shows that the relationship between the two parameters is not quantitative.

Figure 2 shows *Cryptosporidium* log removal and filter effluent turbidity in the three locations. Although excellent filter effluent turbidities were obtained in all cases it is evident that differences in turbidity at these low levels are not quantitatively correlated with *Cryptosporidium* removal capability. A similar result was obtained for filter effluent particle counts (data not shown).

Figures 1 and 2 demonstrate that for well performing filters under stable operating conditions neither filter effluent turbidity nor particle counts can be used as a quantitative indicator of *Cryptosporidium* removal capability. However as the next sections will show, these two parameters have value in predicting changes in *Cryptosporidium* removal capability for a given filter at different points in its cycle or as a result of an operational event. The value of these parameters therefore lies in providing a real-time warning of deterioration in a filter's *Cryptosporidium* removal capability.

Ripening

The ripening period has traditionally been considered one of the vulnerable periods of the filter cycle. It is known that both turbidity and particle counts are elevated during this initial period and therefore strategies such as filter-to-waste have been devised to avoid deterioration of filter water quality.

Figure 3 compares the decrease in *Cryptosporidium* removal to the decrease in particle removal, in comparison to the stable or optimal operating period. This investigation was

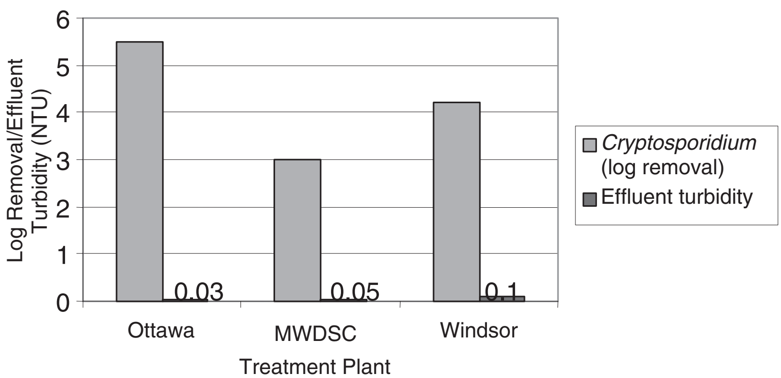

Figure 2 *Cryptosporidium* removals and effluent turbidity values under stable operating conditions

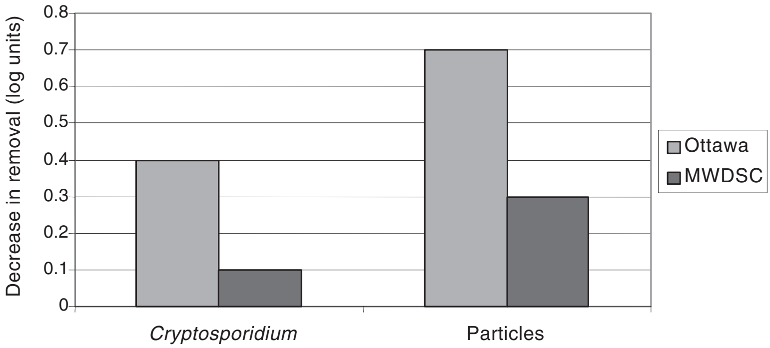

Figure 3 Decreases in removals of *Cryptosporidium* and particles during ripening

conducted at both Ottawa and MWDSC. It is evident that at both locations the decrease in *Cryptosporidium* removal was less than the decrease in particle removal. However, a greater deterioration in particle removal was accompanied by a greater deterioration in *Cryptosporidium* removal. Increases in turbidity also occurred but there was no direct relationship between the decrease in *Cryptosporidium* removal and the increase in turbidity (data not shown).

In both locations the decrease in *Cryptosporidium* removal compared to stable operation was less than 0.5 log units. While this is not an insignificant deterioration, it was not nearly as large as seen during some of the other conditions tested. Although based on results from only two locations, it is encouraging from a process control perspective that the deterioration in *Cryptosporidium* removal was less than the deterioration in particle removal.

Because filter effluent *Cryptosporidium* trends during ripening generally tracked changes in filter effluent turbidity and particle counts (Huck *et al.*, 2001) the common practice of using turbidity or particle counts to decide when to place a filter back online after backwashing would also provide adequate protection against decreased *Cryptosporidium* removal during this period.

Breakthrough

As mentioned previously, the experiments conducted at MWDSC represented end-of-run conditions rather than actual breakthrough. The investigations in Ottawa included the very beginning of the breakthrough period, referred to as onset of breakthrough. Figure 4 shows the decrease in both *Cryptosporidium* removal and particle removal under these conditions. For both locations it is evident that *Cryptosporidium* removal deteriorated more than particle removal compared to stable operating conditions. The decrease in Ottawa was very

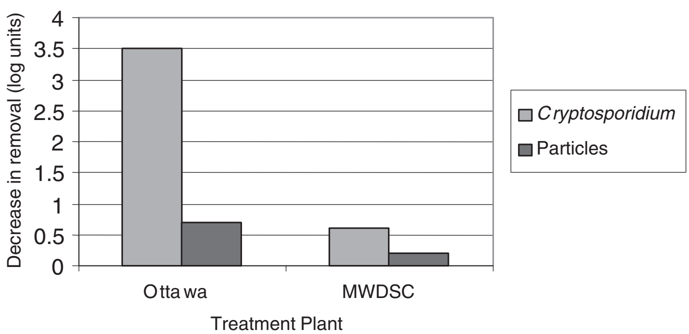

Figure 4 Decreases in *Cryptosporidium* and particle removals during breakthrough

striking, being approximately 3.5 log units. Thus this phase of the filter cycle represents a period where close attention must be paid to even small increases in particle counts.

Suboptimal coagulation

In these experiments the coagulant dose (alum and polymer at MWDSC or alum and activated silica at Ottawa) was reduced 40 to 65 per cent from optimum, in an attempt to achieve a targeted suboptimal turbidity of 0.2 to 0.3 NTU. In some tests, however, the target effluent turbidity was exceeded.

Suboptimal coagulation produced a substantial deterioration in oocyst removal (approximately two log units) in both pilot plants. A similar average reduction was seen in particle removal. When all coagulation conditions were considered, *Cryptosporidium* removal was highly correlated to particle removal at MWDSC (r^2 value of 0.87). At Ottawa, the strength of the correlation was not as high (r^2 0.60). Huck *et al.* (2001) note that the sensitivity of turbidity for monitoring coagulation impacts on oocyst removal may be site specific, and perhaps dependent on the coagulation regime used. They suggest that particle counts may be a more sensitive indicator of poor coagulation performance.

Summary

This paper assesses the relationship of turbidity measurements and particle counts to removals of *Cryptosporidium* by granular media filters. The study examined various points in the filter cycle (ripening, stable or optimal operation and breakthrough) as well as operational effects such as suboptimal coagulation. Data were obtained from pilot-scale spiking studies at two locations. Data from a third location were available for stable operation conditions.

Under stable or optimal conditions filters in all locations performed well, producing average effluent turbidities less than or equal to 0.1 NTU, and low particle counts. However, average *Cryptosporidium* removals varied among locations from 3.0 to 5.5 logs. These results indicate that traditional filter performance measures are not quantitative indicators of *Cryptosporidium* removal capability.

Cryptosporidium removal was impaired under all of the non-optimal conditions. Particle and turbidity performance was also worse, but the relationship of these parameters to *Cryptosporidium* removal varied. During ripening, particle removal deteriorated more compared to stable operation than did *Cryptosporidium* removal. During breakthrough, the opposite was true, and substantial reduction in *Cryptosporidium* removal (several log units) was observed. Thus even small increases in particle counts during this period can be significant. For suboptimal coagulation conditions, average particle and *Cryptosporidium* removals decreased by about an equal extent (about 2 log units).

Increases in turbidity under the non-optimal conditions were less directly related to deterioration in *Cryptosporidium* removal. Thus, particle counts show greater promise as a tool to monitor filter performance in real time for possible deterioration in *Cryptosporidium* removal capability.

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