Comparing crushed recycled glass to silica sand for dual media filtration

Simon O. Rutledge and Graham A. Gagnon

Abstract: The objective of this project was to evaluate the performance of a pressure filter utilizing crushed glass as the filter media in a dual media anthracite–glass filter compared to a dual media anthracite–sand filter. In general, the particle removal capabilities of the crushed-glass filter were slightly poorer than those of a sand filter, as quantified in a field application in the community of Orangedale, Nova Scotia. It was found that the crushed glass used in this project had a higher angularity and slightly higher uniformity coefficient then the sand tested. After 6 months of use the crushed-glass filter was able to produce a filter effluent of 50–70 particles/mL (diameter >2 μm), which is greater than the 25–50 particles/mL (diameter >2 μm) that was produced by sand filter. Over the course of the 6-month study the dual media crushed-glass filter was able to achieve a 1.4-log removal, which was only slightly greater than the dual media silica sand filter that achieved a 1.6-log removal of particles with diameters >2 μm.

Key words: filtration, drinking water, recycled glass, sustainability, particle counting.

Résumé : L'objectif de ce projet était d'évaluer le rendement d'un filtre à pression utilisant de la vitre concassée comme matériau filtrant dans un filtre à double couche anthracite–vitre, par rapport à celui d'un filtre à double couche anthracite–sable. Règle générale, les capacités de retrait des particules du filtre contenant de la vitre concassée était légèrement inférieures à celles du filtre au sable, tel que quantifié par une expérience sur le terrain dans la communauté de Orangedale, en Nouvelle-Écosse. Nous avons constaté que la vitre concassée utilisée dans ce projet était plus angulaire et son coefficient d'uniformité était légèrement supérieur au sable testé. Après six mois d'utilisation, le filtre à la vitre concassée pouvait produire un effluent filtré contenant entre 50 à 70 particules/mL (diamètre supérieur à 2 μm), ce qui est supérieur aux 25 à 50 particules/mL (diamètre supérieur à 2 μm) produit par le filtre à sable. Durant cette étude de six mois, le filtre à double couche à vitre concassée pouvait atteindre un retrait de 1,4 log, ce qui était légèrement supérieur au filtre à double couche au sable de silice, qui a atteint un retrait de 1,6 log pour les particules ayant des diamètres supérieurs à 2 μm.

Mots clés : filtration, eau potable, vitre recyclée, viabilité, comptage de particules.

[Traduit par la Rédaction]

Introduction

Of the total amount of container glass in the Canadian marketplace, estimated at 850 000 t a^{-1}, slightly less than one-half was collected by recycling programs (Glassworks 1999). In Nova Scotia it is estimated that the return rate for beverage containers is over 83%, which represents 216 million beverage containers (Firth 2002). This recycled material is then used in many marketplaces. Presently, recycled glass is utilized as aggregate material for concrete, roadbeds, and pavement; drainage material for backfill and landscaping; production of fibreglass; and as reflective material for paint. The application of crushed glass for filter media is relatively new, and very few studies have reported on its feasibility (Piccirillo and Letterman 1997). If successful, the use of crushed glass could prove important to the postconsumer glass industry, as many industries (e.g., municipal drinking water, on-site wastewater, and industrial process water) rely on filtration for water treatment.

While it is recognized that filter media may lose only 5–7% per annum (AWWA 1998) and the market opportunities for crushed glass may be small in comparison to the postconsumer annual volume. This study is to build on one of the basic principles of industrial ecology, which is that waste from one company is feedstock to another industrial application (Bishop 2000).

Filtration is required for most surface waters to provide a physical barrier and secondary treatment for the transmission of waterborne pathogens. The removal of intestinal parasites, such as *Giardia lamblia* and *Cryptosporidium parvum*, is a critical concern for water treatment plants across Canada. The passage of these microorganisms from source water into drinking water has been suggested as the cause of several reported outbreaks of waterborne disease in the U.S.A. and Canada (Craun et al. 1998).

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In 1994 the US Environmental Protection Agency (USEPA) promulgated the Surface Water Treatment Rule (SWTR), which describes provisions for mitigating against disease-causing microorganisms (Pontius 2000). As described in the SWTR, conventional treatment plants are required to provide a minimum of 3 log (99.9%) of *Giardia lamblia* removal and inactivation and at least 4 log (99.99%) of virus removal and inactivation (Pontius 2000). In the design of rapid sand filters it is common to take a 2-log credit for the removal of *Giardia lamblia* (Droste 1997) and consequently the remaining 1-log inactivation would be achieved through disinfection. Although Canadian water treatment plants are not legally responsible for meeting the SWTR regulation, most plants in Canada use this SWTR as an operational guideline. To assist water treatment plants in assessing filtered water quality, a filtered water turbidity of 0.1 nephelometric turbidity units (NTU) has been recommended as an industry standard (Bellamy et al. 1993). Many Canadian water treatment plants, including the plants that are operated by the Halifax Regional Water Commission, have adopted a filtered water turbidity of 0.1 NTU as a treatment performance indicator.

To achieve the performance goals described in the SWTR, plants must optimize filter operations to achieve the desired removal. Many operational parameters will affect filtration performance, such as physical–chemical properties of the influent water, hydraulic loading rates, physical media properties, and backwashing rates and frequency (Montgomery 1985). Adequate pretreatment is essential for maintaining high quality filter effluent. Any pretreatment interruptions, such as a failure in a coagulant feed pump, caused very quick deterioration in filter effluent quality (AWWA 1999). Transient changes in filtration rate can also impact the effluent quality, as surges in hydraulic loading have been shown to have serious effects on effluent turbidity and other chemical parameters (AWWA 1999). Recognizing that water quality and hydraulic flow parameters may affect filtration, this particular investigation examines the impact of filtration media.

The critical properties of the filter media are media grain size distribution, pore size distribution, shape of the media, surface charge characteristic of the media, viscosity, and other physical characteristics of the media (Droste 1997; AWWA 1999). Alternatives to traditional filtration media have been investigated and include crushed wood charcoal (Agbanobi 1999), crushed quartz (Suthaker et al. 1995), and diatomaceous earth (AWWA 1999). Suthaker et al. (1995) compared quartz to traditional sand and anthracite, and the use of crushed quartz proved to have the best overall performance based on turbidity removal. Crushed glass has been successfully applied as filter media for slow sand filtration (Piccirillo and Letterman 1997). Although the filter hydraulics between slow sand and rapid filtration are significantly differently, it is expected that the present investigation would achieve positive results.

Table 1. Raw and finished water quality for Orangedale water treatment plant.

Water quality parameter	Raw water	Finished water
Alkalinity, mg/L as $CaCO_3$	10	12
Color, TCU	22	<5
Hardness, mg/L as $CaCO_3$	11	11
Iron, mg/L	0.13	0.03
Manganese, mg/L	0.02	0.01
pH	6.8	7.5
Total dissolved solids (TDS), mg/L	33	50
Total organic carbon (TOC), mg/L	6.1	3.0
Turbidity, NTU	2.1	0.1

Note: TCU is true color units; NTU is nephelometric turbidity units.

Objectives

The objective of this project was to determine whether crushed container glass could be used as a water filtration media. This project evaluated the performance of a pressure filter utilizing crushed glass as the filter media in a dual media anthracite – crushed-glass filter, from here on referred to as crushed-glass filter. The performance of the crushed-glass filter was compared to that of a dual media filter containing anthracite and sand, referred to as sand filter. These filters were used in field-scale application for a small community in Cape Breton, N.S.

Materials and methods

Site description

The research was conducted in Orangedale, N.S., which is a small community with a population of approximately 500. Orangedale is located on the south shore of Bras d'Or Lakes that feeds into Miller Pond, which serves as the source of the drinking water. The raw water has an alkalinity of 10 mg/L as $CaCO_3$ and turbidity of 2.1 NTU, as summarized in Table 1.

The Orangedale treatment plant produces an average daily flow of 35 m^3/d (6.4 gpm). The average daily flow changes between summer and winter because of the operation of a summer camp located nearby. Treatment consists of coagulation (sodium aluminate and polyaluminum chloride), flocculation, dissolved air flotation (DAF), disinfection with sodium hypochlorite, and dual-media filtration with anthracite and sand (Fig. 1). As shown in Fig. 1, the clarified water from the DAF tank flows into a disinfection clearwell to provide storage prior to filtration. Water from the clearwell is drawn by high-lift pumps and sent through the pressure filters having a diameter of 0.40 m (16 in.) to the village distribution system on an as-needed basis. Each filter used in the study contained a top layer of anthracite (24 in. deep) and a bottom layer of either silica sand or crushed recycled glass (16 in. deep) with a gravel support layer (4 in. deep). The filters were tested with an average hydraulic loading rate of 5 m/h.

Fig. 1. Schematic of Orangedale Water Treatment Plant.

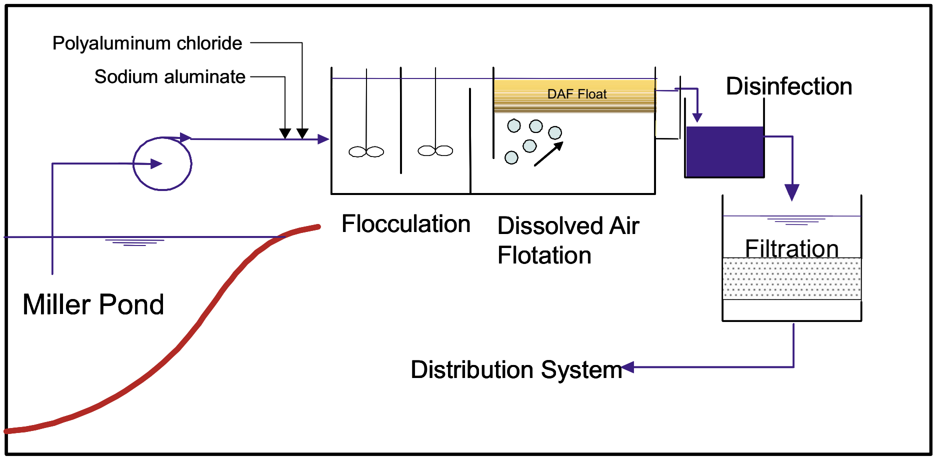
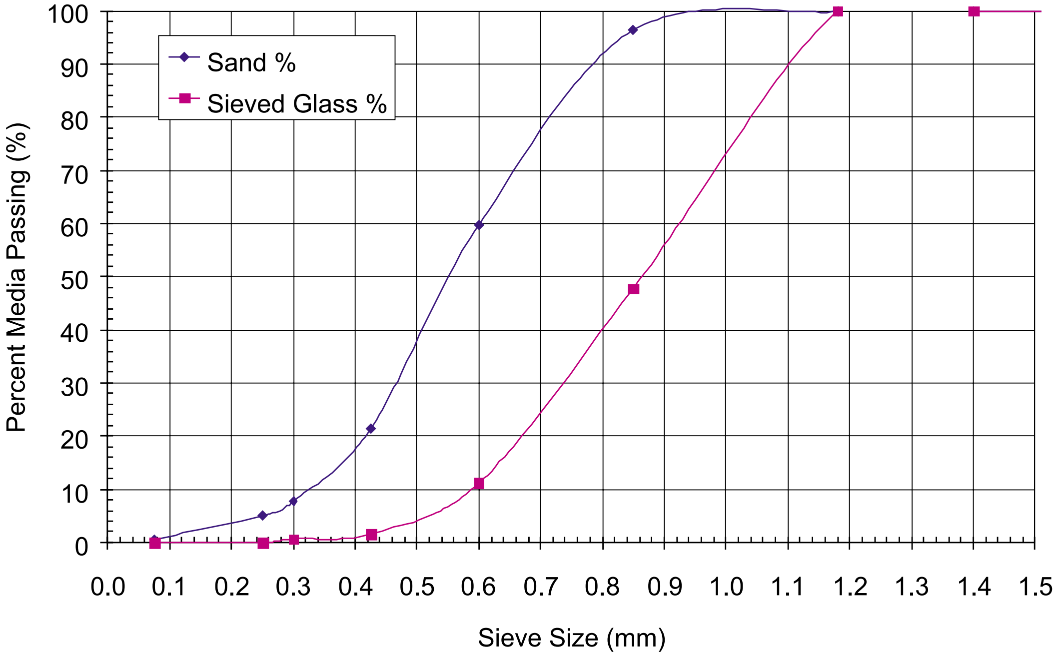


Fig. 2. Sieve analysis of sand and the sieved glass that was used in Orangedale filter study.



The filters were operated in parallel over a 6-month period. During that period the filters were monitored for influent and effluent particle counts for 4-d periods. During the 4-d monitoring period, data were collected for 4 filter runs (i.e., 24-h filter run cycles). Subsequent particle count data were collected from the parallel filter for 4 d before monitoring the original filter again. Nevertheless, both filters were continually operated over the 6-month period.

Characterization of filter media

Sieve analysis was performed on the filter media to determine the size and uniformity coefficient (Fig. 2). The filter sand used in the pressure filter had an effective size (d_{10}) of 0.33 mm and uniformity coefficient (UC) of 1.82. The porosity of the sand was determined to be 0.47.

Crushed glass used in the pressure filter was sieved to provide an initial d_{10} of 0.63 mm and UC of 1.73. The glass was sieved to remove fines and large particles to obtain a d_{10} of 0.59 mm and UC of 1.58. Because the aim of this research was to determine the feasibility of crushed glass, the crushing process was not optimized for processing filter media. Therefore, the majority of the sieving was conducted manually. The specific gravity of the sieved crushed glass was determined to be 2.283, as analyzed using the method described by ASTM D 854. The porosity of the crushed glass was determined to be 0.52.

Consistent with previous studies (Piccirillo and Letterman 1997), the crushed glass had a much higher angularity than the filter sand used in the present investigation. The difference in angularity between the two media types was found through scanning electron microscopy (SEM). The micrograph shown in

Fig. 3. Scanning electron microscopy micrograph of filter sand used in Orangedale field investigation.

Fig. 4. Scanning electron microscopy micrograph of crushed glass used in Orangedale field investigation.

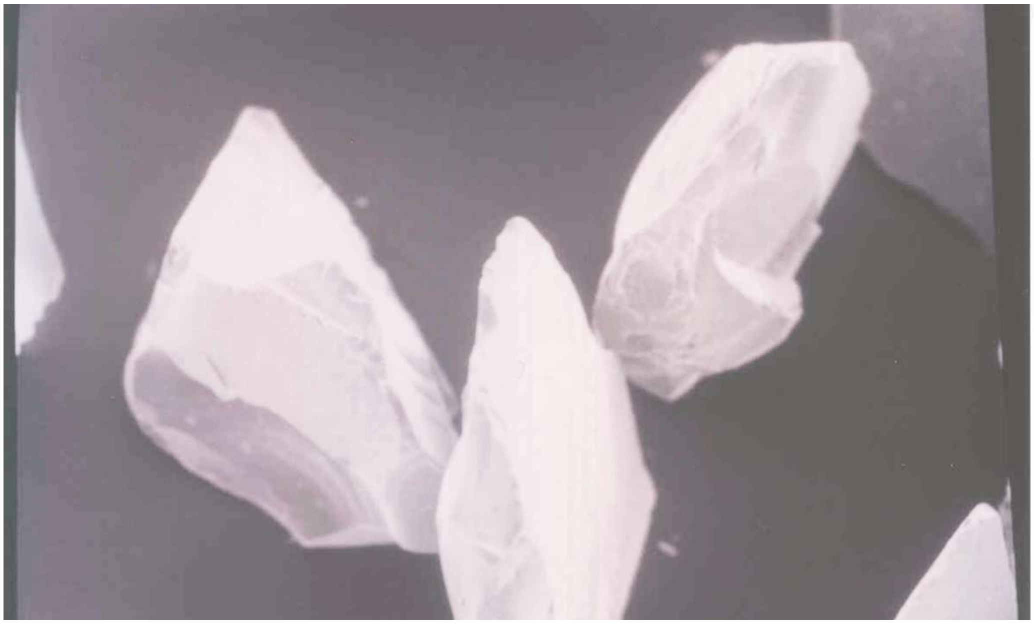


Fig. 3 demonstrates that the sand has a rounded shape, whereas the crushed glass is more angular (Fig. 4). Because of its greater angularity, it is expected that the porosity of the filter containing crushed glass would be slightly higher than the porosity of the filter sand, which has a typical porosity of 0.4 (Droste 1997).

Assessment of filter performance

Quantifying filtration performance has traditionally been performed using only turbidimeters. However, particle counting is becoming more popular because of an increase interest in pretreatment optimization and the ability to accurately monitor filtration and particle removal. Particle counting has been shown to be a more sensitive tool for quantifying filtration performance, especially for lower turbidity levels typical of filtration effluent (Eisnor et al. 2001; Chowdhury et al. 1997). Particle counting has been shown to detect particle breakthrough sooner and to be capable of detecting changes in effluent quality due to minor process changes (Hargesheimer et al. 1998).

The particle counters for this study were HACH 2200 PCX (HACH Corp Lovelaud CO) and were used to analyze raw water, filter influent, and filter effluent water. The particle counter uses light extinction technology for sizing and counting particles.

Fig. 5. Particle counts for a filter run in the crushed glass summer sample period.

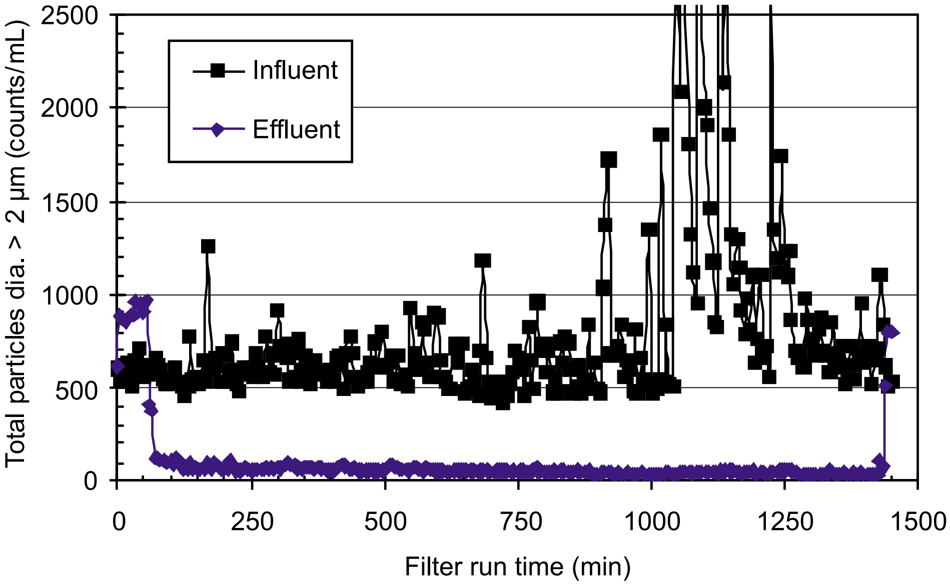
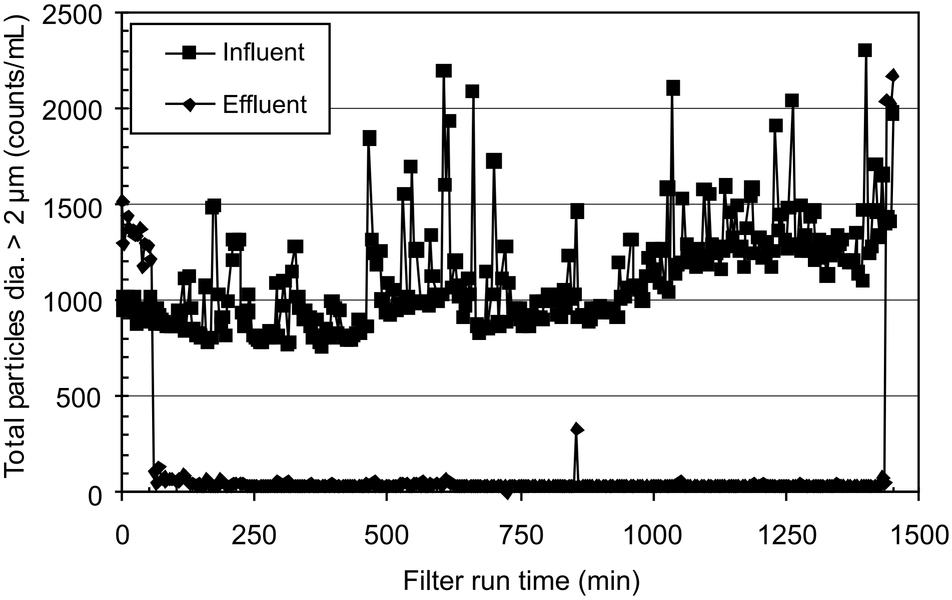


Fig. 6. Particle counts for a filter run in the sand filter during summer sample period.



Data collection and analysis

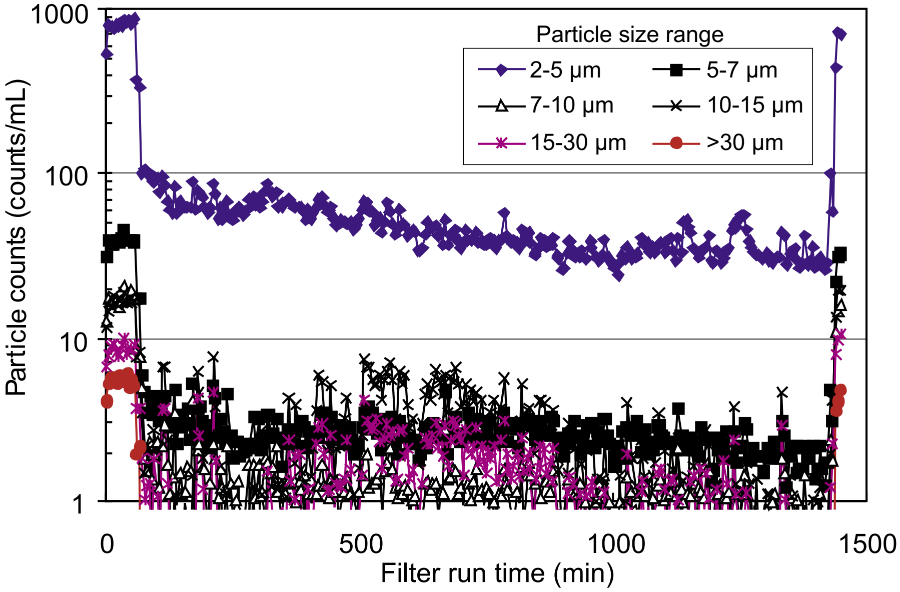
An on-site laptop installed with Vista Soft (Hach, Corp., Loveland, Colo.) was used to log the data from the Hach 2200 PCX particle counters. The software was set to take readings every 2 min and to record the readings every 5 min during the summer series and every 10 min during the winter. The software and particle counters were set up to record 2–5, 5–7, 7–10, 10–15, 15–30, and >30 μm.

Results and discussion

Evaluation of filter run

Figures 5 and 6 show the filter influent and effluent particle counts for particles >2 μm in diameter over the summer filter runs for the crushed glass and silica sand filter, respectively. As shown in Fig. 5, particle counts of 800–1000 are initially recorded over the period from 0 to 50 min, which is indicative of a backwash event. During filter backwashing the filter media is being cleaned of particle build up and is not supplying water to the town. After the filters have finished backwashing, influent water is applied to the filter and the filters undergo a ripening period until they reach a steady-state quality of effluent. For the glass filter shown in Fig. 5, ripening occurs over the period of 50–100 min. During steady-state filtration, the crushed-glass filter provided an effluent concentration of 40–60 particles/mL for the filter run shown in Fig. 5. The steady-state filter effluent was consistent in spite of significant increases in influent particulate matter.

Fig. 7. Distribution of effluent particle sizes from the glass filter during summer sample period.



Similar to the filter containing crushed glass, the sand filter undergoes a ripening period. The steady-state filter effluent water, as quantified by enumerating particles >2 μm from the sand filter, was in the range of 25–50 particles/mL for the filter run shown in Fig. 6.

The data presented in Figs. 5 and 6 provide an indication of the level of treatment for removing suspended particles that have a diameter >2 μm. Because there is great interest in the ability of filters to remove *Cryptosporidium parvum* and *Giardia lamblia,* particle counting data are also used as tools to provide estimates by quantifying particle removal in the 2–5 μm diameter range (i.e., similar size to *Cryptosporidium parvum*) and in the 5–15 μm diameter range (i.e., similar size to *Giardia lamblia*). Figure 7 shows that the majority, >95%, of the effluent particles were in the 2–5 μm diameter size range for the filter containing crushed glass, which is consistent with data presented for four rapid sand filters that were studied by O'Leary et al. (2002). As shown in Fig. 6, the effluent number of particles gradually decreased from 90 particles/mL to <50 particles/mL over the course of the filter run.

Consistent with the crushed-glass filter, the sand filter had the greatest concentration of effluent particles in the 2–5 μm size range (Fig. 8). In general, the sand filter had lower number of particles in the 2–5 μm size range in the sand filter in comparison to the crushed-glass filter. Figure 9 presents the average particle count data for the steady-state periods of the filter runs shown in Figs. 7 and 8. Although the number of particles in the 2–5 μm size range is lower in the sand filter, on average the particles in the 5–7 μm size range were slightly greater in the sand filter than in the filter containing crushed glass. At sizes >10 μm, however, the sand filter provided better particle removal. Because of the more angular nature of the glass, it is plausible that the crushed-glass filter is more effective for small particle size range than conventional filter media, such as silica sand.

Filter ripening

The rate at which a filter achieves optimal filtration, or ripening period, is of particular concern because it may indicate an increased risk of pathogen breakthrough and (or) public health risk. During nonoptimal operating conditions, filters have been shown to have poor pathogen removal capabilities (Huck et al. 2001). The ripening periods for both filters are provided for the summer and winter sampling campaigns in Figs. 10 and 11, respectively. For both periods it was found that the sand filters were able to ripen in less than 10 min, whereas the crushed-glass filters ripened in 15–20 min. It is likely that the more angular of the crushed glass resulted in longer settling time and in a longer period of time required to form a filter cake, which is consistent with the slightly longer start-up periods that were reported for slow sand filters (Piccirillo and Letterman 1997).

Overall performance and log removal of particles

To assess the overall performance of each filter, total particle counts (particles >2 μm in diameter) and log removal during a filter run were compared for both summer and winter sampling campaigns.

The effluent particle counts for all of the filter runs during the summer and winter sampling campaigns were analyzed using Box and Whisker analysis (Fig. 12). The lower line of boxes shown in Fig. 12 represent the 25th percentile of particle counts (i.e., 25% of the effluent particles had a diameter less than the lower box). Similarly the upper line represents the 75th percentile of the total particle counts. The lines, or the whiskers, stemming from the boxes in Fig. 12 represent the maximum and minimum particle counts during the steady-state filter operation (i.e., excluding particles counted during ripening and backwashing).

Figure 12 shows that regardless of temperature the sand filter was able to achieve relatively similar total effluent counts in the

Fig. 8. Distribution of effluent particle sizes from the silica sand filter during summer sample period.

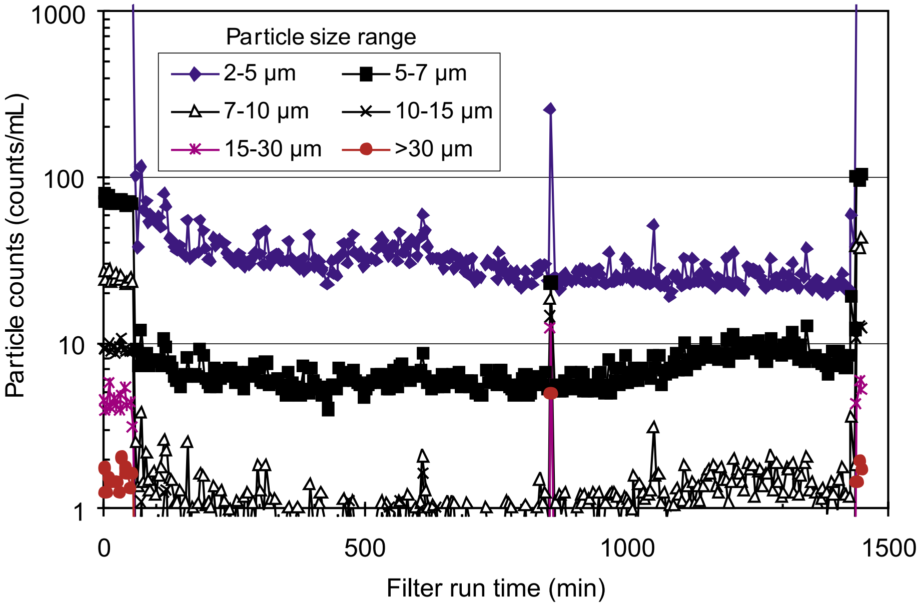
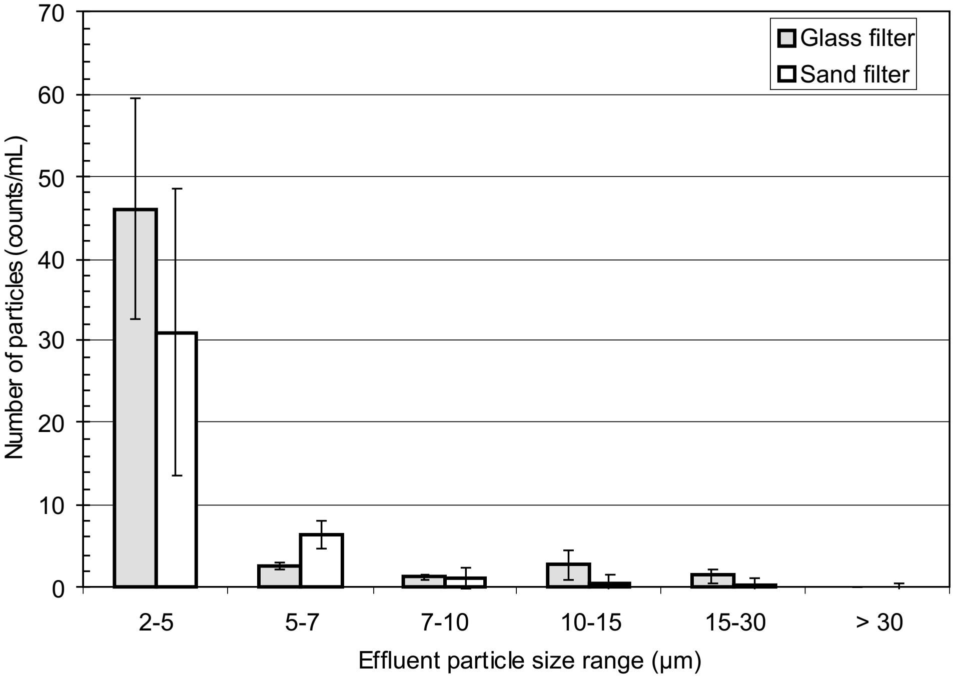


Fig. 9. Average size distribution of effluent particles from the crushed glass and silica sand filter (error bars represent one standard deviation).



range of 15–70 counts/mL. The particle counts for the crushed-glass filter in the warm sampling period had a much larger range than during the winter. In the summer the filters were first installed with fresh media. Therefore, it is suspected that the discrepancy for particle removal in the glass filters are related to wear and rounding that the glass has undergone during 6 months of filter operation, which would lead to improved filter removal. Similarly, the sand filter also improved with aging.

In addition to effluent filter counts the log removal of particles was also evaluated. Because there are no guidelines established for particle counting, the significance of a filtered water particle count value is difficult to evaluate. Therefore, to determine the relevance of the filtration process from a practical perspective the log removal of particles with a diameter >2 μm was calculated. Log removal was determined by

$$[1] \qquad \text{Log removal} = -\log\left(\frac{\text{effluent particles}}{\text{influent particles}}\right)$$

The advantage of calculating log removal is that the variance in particle counter performance among manufacturers that has

Fig. 10. Comparison of filter ripening characteristics for the crushed glass and sand filter during summer sample period.

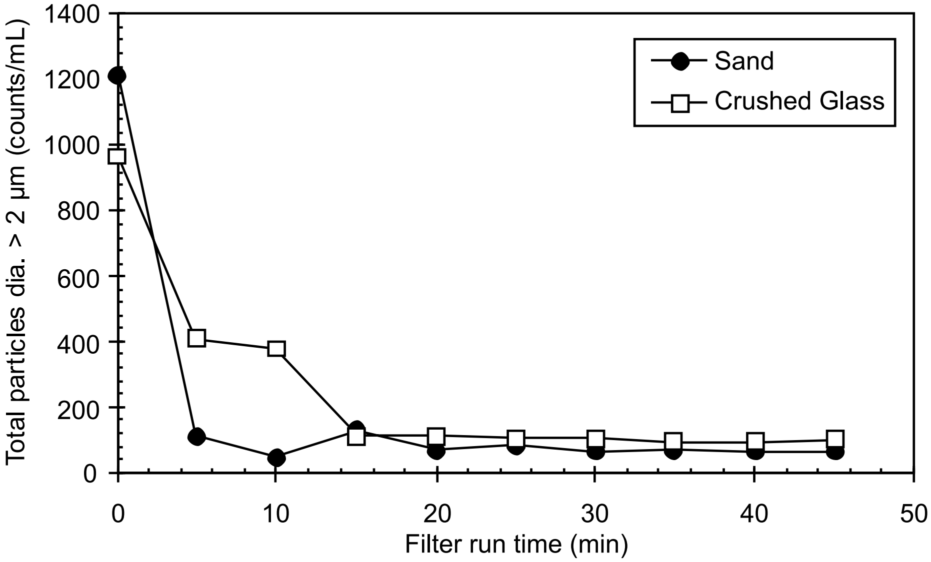
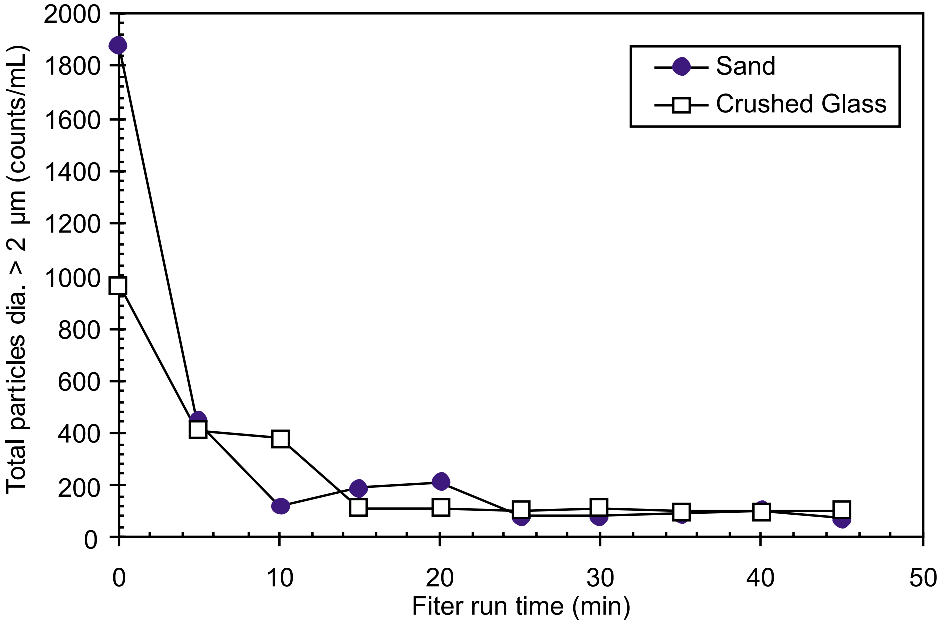


Fig. 11. Comparison of filter ripening characteristics for the crushed glass and sand filter during winter sample period.



been reported in literature (Van Gelder et al. 1999) is reduced because this form of data analysis is a relative removal rather than absolute removal. However, caution should be used when using relative removals for design and operation. For example, a plant that has a raw water and filtered effluent particle count of 100 000 particles/mL and 1000 particles/mL, respectively, would report a 2-log removal (i.e., 99% removal) of particles. Similarly, a plant with a raw water and filtered effluent particle count of 10 000 particles/mL and 100 particles/mL, respectively, would also report a 2-log removal by filtration. Although both filters are removing the same percentage of particles or log removal, the former plant has a higher number of filtered water particles, which is indicative of poorer water quality and an increased vulnerability to a breakthrough of waterborne pathogens. Nevertheless, in North American practice, it is common to receive a disinfection credit for 2-log removal of *Giardia lamblia* for having filtration in the treatment train (Droste 1997).

Figure 13 provides the log removal values for the sand crushed-glass filter during steady-state operation. As shown in Fig. 12, the crushed filter provided lower log removals of particles >2 μm in size during the warmer months. However, as the glass became worn, log removal improved by one-quarter of a log, which suggests that if the glass underwent pretreatment rounding prior to packing the performance could be consistent with silica sand.

In general, the application of crushed glass shows considerable promise as filter media for the water industry. This would

Fig. 12. Box and whisker comparison of sand and crushed-glass filter performance.

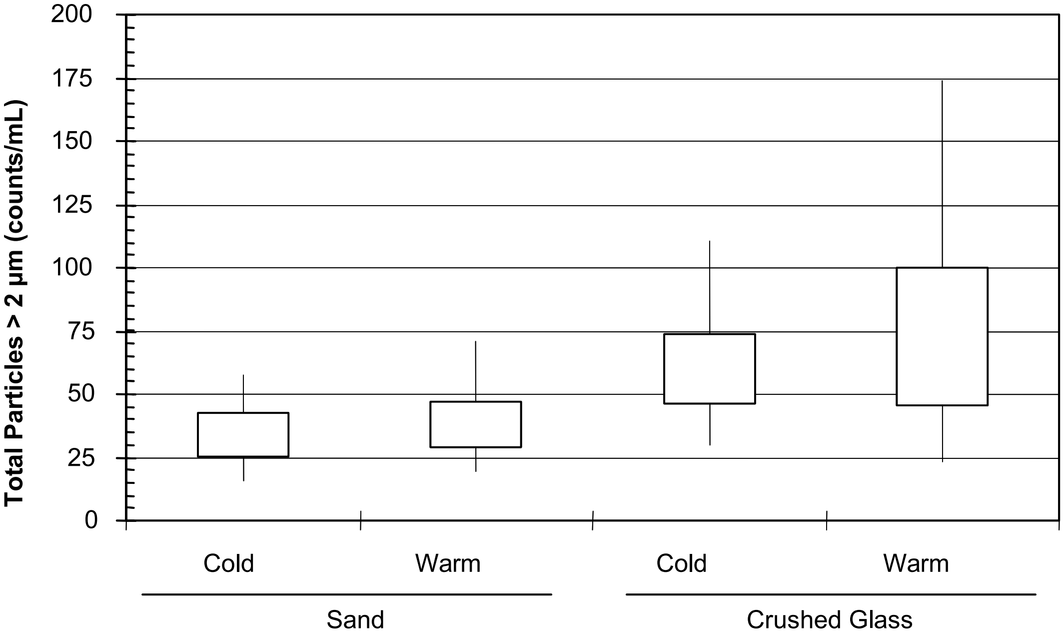
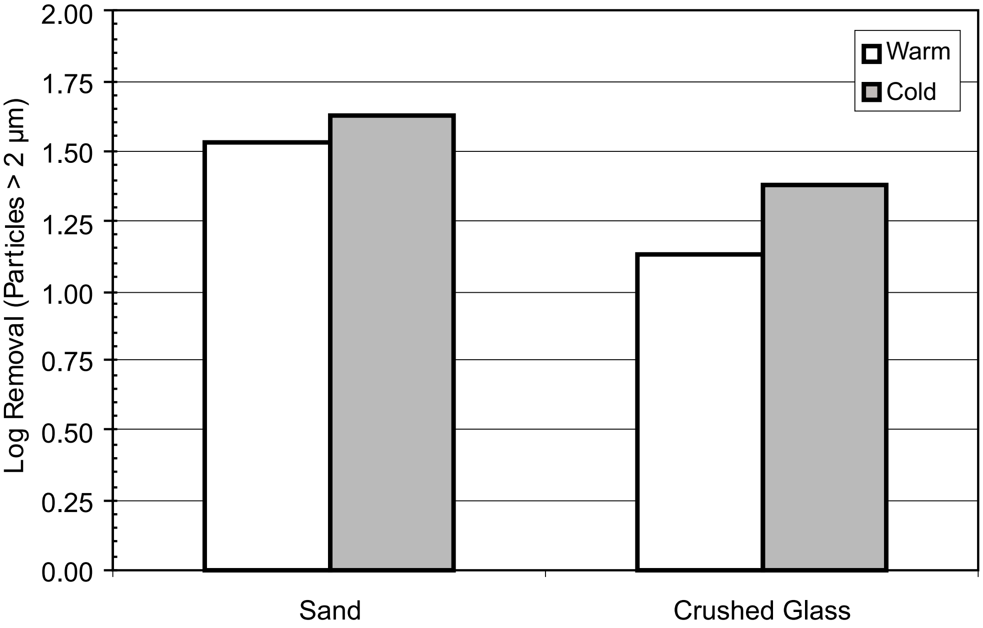


Fig. 13. Log removal of total particle counts for the sand and crushed-glass filter.



be particularly true for remote areas that may not have access, either due to economic considerations or regional geology, to silica sand. However, prior to full-scale implementation of crushed glass, it is recommended that further testing be conducted to determine the life cycle of crushed glass relative to silica sand. In addition, the testing should also determine if the crushed glass can provide value-added component(s) (e.g., electrical potential, for metals removal), which may not be present in silica sand. Life-cycle expectancy would be essential for providing full-cost accounting for future designs involving crushed glass.

Conclusions

This project investigated the performance of crushed glass as an alternative filter media to silica sand. In general, the particle removal capabilities of the crushed-glass filter were slightly poorer than those of a sand filter, as quantified in a field application in the community of Orangedale, N.S. It was found that the crushed glass used in this project had a higher angularity and slightly higher uniformity coefficient than the sand.

Compared to sand the initial start-up performance of the crushed-glass filter was more variable and appeared to improve as the glass began to wear. After 6 months of use the crushed-glass filter was able to produce a filter effluent of 50–70 particles/mL (diameter $>2\ \mu$m), which is greater than the 25–50 particles/mL (diameter $>2\ \mu$m) that was produced by sand filter. After 6 months of use, the sand filter achieved a 1.6-log removal of particles with diameters $>2\ \mu$m, whereas the crushed-glass filter achieved a 1.4-log removal for the similar particle size range. The observed removal performance was particularly encouraging, given that the sand used had properties that were consistent with the standards set by the American Water Works Association. The crushed-glass filter media was initially sieved and washed, but had no other pretreatment preparation. Therefore, further work in improving the efficiency examining the durability and evaluating the market application to drinking water is critical.

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