Use of recycled crushed glass as a filtration medium in municipal potable water treatment plants

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Abstract The aim of this study was to investigate the use of recycled crushed glass as a filtration medium for municipal potable water treatment plants. It evaluated the main physical parameters of recycled glass and its performance in a potable water treatment application. Pilot-plant testing was used to compare the performance of recycled glass to a typical sand filter medium in a conventional treatment process. Laboratory analysis was used to determine media characteristics. Pilot-plant testing determined that the filtration performance of the glass medium was similar to that of a typical sand medium of similar effective size and uniformity under all conditions tested. The glass medium had the benefit of taking 10–15% longer than the sand to reach particle breakthrough. The glass also appeared to accumulate headloss in most runs at a slightly lower rate than the sand. Backwashing observed during pilot-plant testing also showed that the glass expanded more than the sand under the same backwash water rates. This was noted to be a potential benefit to installations that have low backwash water flow.

Keywords Bed ripening; filtration media; headloss; metals removal; recycled glass; water treatment

Introduction

Recycled glass media have been identified for possible use in municipal drinking-water treatment plant filters. This study involved a pilot-plant program to compare the relative performance of crushed recycled glass with conventional sand media for the filtration of potable water.

Experimental

Pilot plant

The pilot plant used in the study has the capacity to simulate several different full-water treatment processes, such as conventional treatment and contact/direct filtration. Conventional treatment process filter-media configurations were tested in the pilot plant study. Pre-treated, clarified water was obtained from Hunter Water's Grahamstown Water Treatment Plant (GWTP) (Figure 1).

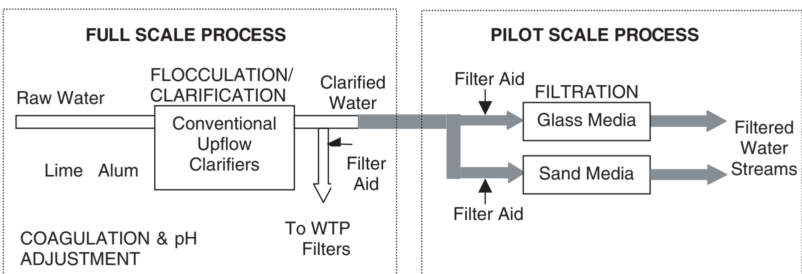

Figure 1 Schematic of conventional treatment process used in pilot study

Feed water for the pilot plant columns was taken from the common filter inlet channel transferring water between the clarifiers and the filters of GWTP. The water was bore water drawn from Tomago Sandbeds. This groundwater is often high in iron. Feed water quality characteristics for the period of the pilot trials are summarised in Table 1. It should be noted that feed water used in the pilot-plant trials was partly treated, with coagulant dosing and settling before the pilot-plant feed water tank. The quality of the feed water varied at times during the study, owing to changes in the incoming raw water quality (different bores are used to supply the plant) and changes in the pre-treatment process, such as lime and alum dosing.

The two filter columns at the Grahamstown pilot plant allow the simultaneous comparison of two alternative filter media configurations. Recycled glass medium was installed in one filter column and typical filter sand medium was installed in the other. Each column was part of one of two identical pilot-plant process streams. A schematic diagram for one stream of the pilot-plant setup is shown in Figure 2. Clarified water was pumped from the single-feed water tank into the head tanks of each of the two process streams using two centrifugal pumps. The water then gravitated through the filter media in the filter columns, and into the control tanks. Each control tank inlet was fitted with a float valve to maintain a constant level. The flow rate through each filter was set by adjusting the filtered water flow control valve downstream of the control tank. The control tanks maintained a constant filtered water flow rate, regardless of the pressure drop over the filter. Filtered water was collected in the clear water tank and was stored for backwashing the filters. The pilot-plant filter columns were constructed of acrylic tubing of 140 mm internal diameter. The

Table 1 Feed water quality summary

Parameter		Units	Range during trials
Turbidity		NTU	1.3–5.5
Colour (true)		PtCo	5–10
pH		–	6.9–7.7
Particle count		Particles/mL	1,500–1,900
Iron	– total	μg/L	320–1,700
	– soluble	μg/L	30–310
Manganese	– total	μg/L	32–51
	– soluble	μg/L	36–48
Aluminium	– total	μg/L	400–860
	– soluble	μg/L	40–80
Feed water temperature		°C	14–18

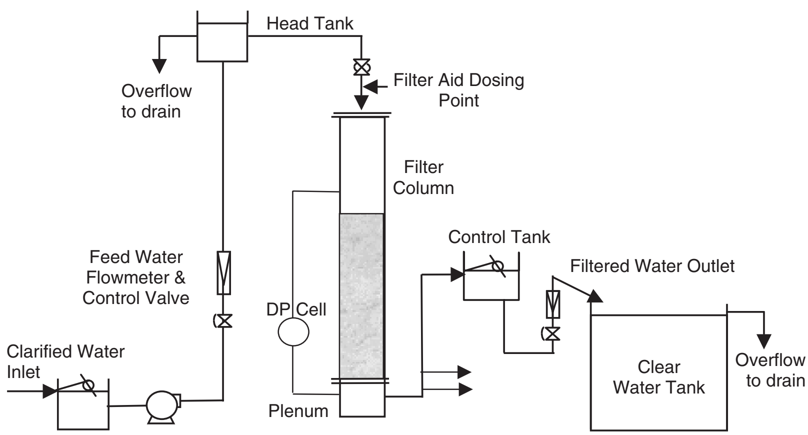

Figure 2 Pilot plant process stream – filtration mode

columns were designed to simulate a cross-section of a full-scale filter bed. The filter medium was placed over a graduated bed of gravel, which supported the media and aided in the distribution of backwash air and water over the area of the column. A single-filter nozzle underneath the gravel layer drained the filtered water into a plenum section, in a similar manner to full-scale filters of plenum underdrain design.

The media configurations installed in the filter columns for this study are summarised in Table 2. Note that the effective size and uniformity coefficients quoted are for the material after an initial backwash was done to remove fines and foreign material.

Monitoring of run data and performance assessment

On-line instrumentation on the pilot plant provided continuous monitoring of: filtered water turbidity, filtered water particle counts, and differential headloss in the filters. Trends in these on-line parameters were recorded by a data logger and transmitted to a personal computer that stored the data for each run and allowed real-time display of the results in graphical form. Filtered water turbidities were monitored using on-line turbidity meters sampling from the filter outlet pipes. The waters were returned to the appropriate control tanks. Filtered water particle counts were monitored using on-line particle counters fitted with "water weir" devices to control the rate of flow through the counter units. Samples were taken from the filter outlet pipes and returned to the appropriate control tanks. The headloss across each filter bed was monitored using a differential pressure (DP) cell connected to pressure tappings above and below the media in each filter column. Grab samples of water were collected and analysed for both feed and filtered water turbidity and particle counts (for comparison with on-line readings), and pH, colour and metals (iron, manganese and aluminium). The performance criteria used to compare the performance of the filter media types were: run time, unit filter run volume (UFRV), filtered water quality (Included turbidity, particle counts, pH and iron, manganese and aluminium levels), ripening time, and total and rate of accumulated headloss.

Run termination criteria

Pilot plant run termination was based on either one or a combination of: (1) headloss accumulation to a terminal level (≥ 3.0 m), turbidity breakthrough or rise to a terminal level (≥ 0.30 NTU), or (3) operation time (≥ 25 hours). While particle counts are also a valuable measure of water quality, they are not widely used as criteria for run termination in full-scale water treatment plants, and are not covered by the 1996 Australian Drinking Water Guidelines. Consequently, they were therefore not used as criteria for run termination in this study.

Table 2 Filter media configurations compared in testing

	Sand media	Recycled glass media
Media identification	River sand	Bronze blast glass media
Supplier	Brisbane river sands	Visy recycling
Effective size (mm)		
(as measured by HWA La.)	0.97	0.98
Uniformity coefficient		
(as measured by HWA Lab.)	1.27	1.31
Depth installed in pilot plant column (mm)	900	900
Support gravel layers (mm)	2–3 mm/100 mm	2–3 mm/100 mm
(effective size/layer depth)	3–6 mm/100 mm	3–6 mm/100 mm
	6–12 mm/100 mm	6–12 mm/100 mm
	12–24 mm/100 mm	12–24 mm/100 mm
Pilot plant filtration stream	Stream 1	Stream 2

Results and discussion

Filtered water turbidity and particle counts

A summary of the pilot-plant filter runs is given in Table 3. Filtered water turbidities of less than 0.2 NTU were produced in all runs while the filtration process was stable (after ripening and before breakthrough), with on-line readings typically of 0.1 NTU for most runs. Slightly higher filtered water turbidities were noted during higher feed water turbidities, however all filtered water turbidity levels were within typical target levels (<0.3 NTU) for drinking water treatment processes, and well below the 1996 Australian Drinking Water Guideline (ADWG) recommended level of <1 NTU. There were no significant differences between turbidities produced by the glass and by the sand media types, as seen in Table 4.

The on-line particle counter for the sand media filter was not functioning correctly until run CHC04. Thereafter, particle counts followed a similar pattern for both media types. In all runs, filtered water particle counts less than 50 particles/ml were achieved while the run was stable. Particle counts achieved by the glass media were the same or slightly lower than

Table 3 Summary of pilot plant runs undertaken

Run No.	Start date	Filter No.	Filter media type	Filtration rate (m/h)	Filter aid dose (mg/L)	Run time (hours)	Reason run ended
CHC01	7/8/00	1	Sand	7.5	–	>25	Time
		2	Glass	7.5	–	>25	Time
CHC02	8/8/00	1	Sand	10	–	>25	Time
		2	Glass	10	–	>25	Time
CHC03	9/8/00	1	Sand	12.5	–	14.7	Tb >0.3
		2	Glass	12.5	–	14.6	Tb >0.3
CHC04	10/8/00	1	Sand	12.5	–	13.7	Tb >0.3
		2	Glass	12.5	–	13.6	Tb >0.3
CHC05	15/8/00	1	Sand	12.5	0.025/0.05	9.2	Tb >0.3
		2	Glass	12.5	0.025/0.05	9.2	Tb >0.3
CHC06	16/8/00	1	Sand	12.5	0.1	6.4	HL>3 m
		2	Glass	12.5	0.1	6.5	HL>3 m
CHC07	17/8/00	1	Sand	12.5	0.05	6.2	HL>3 m
		2	Glass	12.5	0.05	4.7	HL>3 m
CHC08	17/8/00	1	Sand	12.5	0.015/0.03	5.5	Tb 0.3
		2	Glass	12.5	0.015/0.03	5.5	Tb

Table 4 Typical turbidities and particle counts during pilot testing

Run No.	Media	Turbidity (NTU)		Particle counts	
		Filtered water	Raw water	Filtered water (P/mL)	Feed water (P/mL)
CHC01	Sand	0.04	2	–	1,500
	Glass	0.04		<10	
CHC02	Sand	0.07	1.9	–	1,900
	Glass	0.07		35	
CHC03	Sand	0.06	2.5	–	1,700
	Glass	0.07		20	
CHC04	Sand	0.09	2.7	45	1,500
	Glass	0.11		45	
CHC05	Sand	0.1	4.0	45	–
	Glass	0.1		37	
CHC06	Sand	0.05	4.3	20	–
	Glass	0.05		20	
CHC07	Sand	0.07	2.5	12	–
	Glass	0.04		11	
CHC08	Sand	0.09	2.5	15	–
	Glass	0.05		15	

those produced by the sand media. Feed water particle counts were also measured manually for the runs CHC01–04. Log particle removal of particles was calculated using typical filtered water particle counts measured on-line and typical feed water particle counts measured from grab samples analysed on a bench particle counter. 2-log removal of particles was achieved on runs CHC01–04. It is expected that log removals for runs CHC05–08 would also be about 2.

Ripening times

Ripening times for turbidity varied between 0.7 and 2.7 hours over all runs. Ripening times were generally the same for the glass and sand media types in each run. No trends in ripening times corresponding to filtration rate were observed. Ripening time decreased significantly in the last two runs, when the filter media is likely to have been conditioned with polymer from previous runs. The turbidity ripening times observed were significantly greater than would be the target at most water treatment plants. Generally, ripening times of less than 0.5 hours would be desired in a water treatment plant. Runs CHC07 and CHC08 were approaching these times. Ripening times are reduced by polymer dosing to the feed water, and may be further reduced by other measures such as dosing polymer into the backwash water. Particle count ripening times were also noted. These ripening times were generally less than the turbidity ripening times in runs without filter aid dosing, and greater than the turbidity ripening times in runs with filter aid dosing. They varied between 0.6 and 3.2 hours, and were on average the same for both filter media types. As for turbidity, an improvement (reduction) in ripening time was noted for the last two pilot-plant runs.

Turbidity and particle breakthrough

Turbidity and particle breakthrough occurred for both types of media in all runs at a filtration rate of 12.5 m/h, except those at the higher filter aid polymer doses of 0.05 and 0.1 mg/L. In runs at the lower filtration rates of 7.5 m/h and 10 m/h, a rise in turbidity commenced after 15 hours and 7 hours respectively; however, the turbidity did not reach the terminal level of 0.3 NTU before the runs were ended due to time. Particle breakthrough to 100 particles/mL or more occurred in both runs at the lower filtration rates and all 12.5 m/h runs, except those at filter aid doses of 0.05 and 0.1 mg/L. The pattern of turbidity breakthrough in runs without filter aid dosing was generally a slow rise in turbidity, (occurring over 10 hours or more), from around 0.1 NTU to 0.3 NTU. Where breakthrough occurred in runs with filter aid dosing (at doses of 0.015 and 0.025 mg/L), the rate of turbidity rise to terminal level occurred more rapidly (over approximately 5 hours). Particle breakthrough (reaching 100 counts/ml) occurred an hour or more before turbidity breakthrough in all cases except at filter aid doses of 0.05 and 0.1 mg/L. Particle breakthrough normally occurs before turbidity breakthrough in full-scale WTP filters. The slope of the particle breakthrough rise was steeper than that for turbidity breakthrough but was similar for both glass and sand. Importantly, it was noted that particle breakthrough consistently occurred 10–15% later for the glass than for the sand. This is a significant result because of the likely greater emphasis on particle counting as a criterion for run termination in full-scale WTPs in future.

Metals removal

Filtered water metals levels are summarised in Table 5. The table also shows target metals levels generally adopted in water treatment applications. The levels of iron, manganese and aluminium exceeded typical target levels on several occasions. Iron and manganese levels were generally less than the Australian Drinking Water Guideline (ADWG) recommended levels for these metals. Aluminium levels exceeded the aesthetic ADWG level of 100 µg/L in several runs, even at the lower filtration rate of 10 m/h (Run CHC02). High metal levels

Table 5 Metals targets and typical levels achieved in pilot testing

Run No.	Media type	Iron total/sol (μg/L)	Manganese total/sol (μg/L)	Aluminium total/sol (μg/L)
Typical treated water target level		*< 100*	*< 20*	*< 100*
ADWG (1996) aesthetic-based level		*< 300*	*< 100*	*< 100*
CHC01	Sand	60	37	75
	Glass	70	38	95
CHC02	Sand	70	31	110
	Glass	70	32	120
CHC03	Sand	120	31	141
	Glass	90	32	142
CHC04	Sand	120	33	153
	Glass	110	33	118
CHC05	Sand	90/20	39/39	105/45
	Glass	90/30	42/37	73/59
CHC06	Sand	130/100	55/50	32/24
	Glass	200/180	53/53	44/24
CHC07	Sand	30	32	44
	Glass	40	32	38
CHC08	Sand	40	33	37
	Glass	140/60	33/35	57/38

are commonly associated with floc breakthrough or less than optimum coagulation conditions rather than filter media performance. It was noted that the WTP coagulation and flocculation process upstream of the pilot were not ideal during some periods of testing due to variable raw water quality and plant failures. The pilot plant feed water pumps may also have adversely affected the floc characteristics.

Effect of filtration rate on run times and UFVRs

The performance of the filters without filter aid under the different filtration rates tested is summarised in Figure 3. There was virtually no difference between the sand and glass media based on filter run time or UFRV at each filtration rate. The highest UFRV values were achieved with a filtration rate of 10.0 m/h, indicating that this filtration rate would produce the most filtered water per run. The runs at 7.5 m/h and 10 m/h were stopped based on time (25 hours) rather than turbidity breakthrough or terminal headloss. The final UFRV may have been higher if the run was allowed to continue further. Filters would not

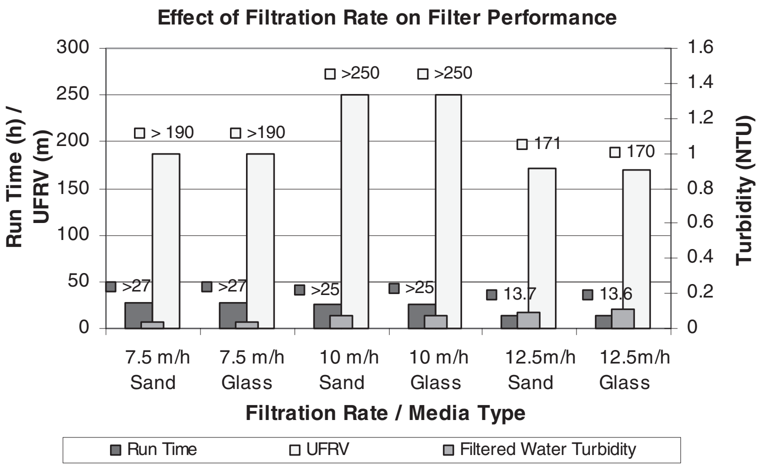

Figure 3 Effect of filtration rate on filter performance

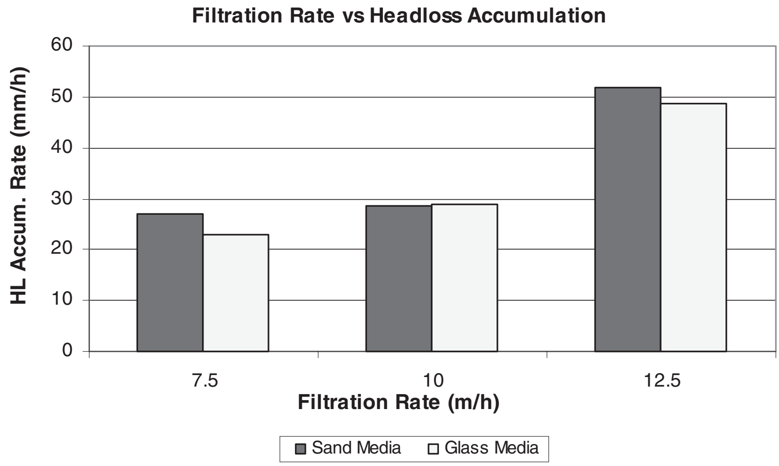

Figure 4 Effect of filtration rate on headloss accumulation rate

normally be run longer than this due to the risk of creating anaerobic conditions in the filter (which can lead to taste and odour problems). The filtration rate of 7.5 m/h is, however, more typical of rates used in conventional treatment processes. The filtered water turbidity level was noted to increase slightly as the filtration rate was increased.

Headloss accumulation rates

Figure 4 compares the headloss accumulation rates for the different filtration rates trialed (without filter aid polymer). As expected, the headloss accumulation rates were greater for the higher filtration rates. The headloss accumulation rate for the glass medium ranged from virtually the same as the sand medium, to 15% less than the sand. The lower headloss accumulation rate could potentially increase the run time of the glass media.

Backwash expansion

The expansion of the media beds during the backwashing water washing phase was measured at different backwash rates several times during the testing program. The results from backwashing observations before the start of testing (Pre-Tests) and after run CHC05 are summarised in Figure 5.

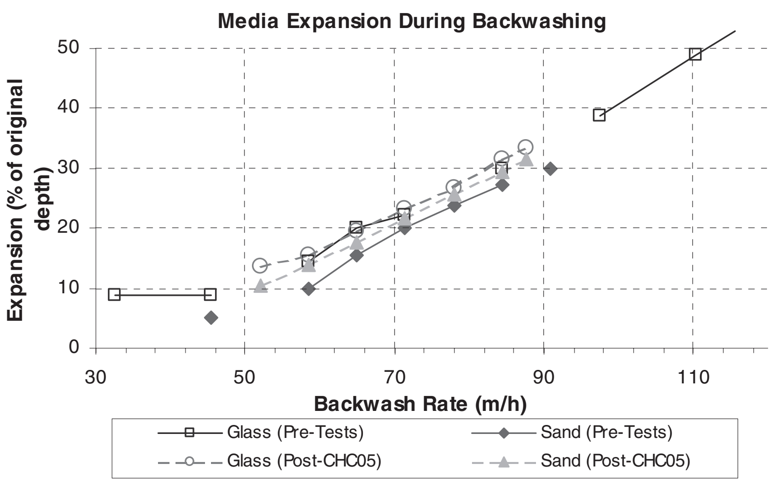

Figure 5 Observed media expansion during backwashing

It can be seen that the glass media expanded 10–20% more than the sand at the same backwash rates. This is related to the lower density of the glass material. Also, the rates of expansion in the post CHC05 tests were somewhat higher than the pre-testing expansion for the sand media. This difference in backwashing performance may be attributed to several factors, including: the use of filter aid polymer in run CHC05, and mixing of the media with the smallest size support gravel.

Conclusions

Several conclusions can be drawn from the pilot-plant study of recycled glass and typical sand filter media. Firstly, the glass medium generally produced water of equal quality to the sand in terms of turbidity, particle counts and metals content. Secondly, glass had the benefit of a longer time to particle breakthrough and headloss in the glass filter was up to 15% less than in the sand. Thirdly, the glass media required 10–20% lower backwash flow rates to achieve the same bed expansion as the sand during the water wash phase of backwashing. However, it was observed after runs with filter aid polymer that the glass media required a longer time (and therefore a greater backwash water volume) to wash clean than the sand.

The greatest potential use for glass media in potable water treatment is seen to be in replacing sand in conventional mono-media filters. There is some threat to future market size, however, due to newer dual-media filters and technologies such as membranes. At current prices, the glass medium is of comparable cost to sand medium ex works, while it is expected that increased use of glass in filters has the potential to lower the unit cost.