APPLICATION OF DIRECT FILTRATION TO MIEX® TREATED RIVER MURRAY WATER

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EXECUTIVE SUMMARY

Dissolved natural organic matter (NOM) has been shown to interfere with the coagulation process, particularly with alum (aluminium sulphate) which is the most widely used coagulant in potable water treatment. The additional coagulant demand of the NOM can often be a significant contribution to the overall coagulant dose required for effective turbidity control in conventional water treatment.

The MIEX® DOC (Magnetic Ion Exchange Resin) process, jointly developed by SA Water, CSIRO and Orica Australia Pty. Ltd. has been shown to be efficient for the continuous removal of NOM from water supplies. By applying this technology upstream of the conventional treatment train, numerous benefits can be achieved, including a reduction in the coagulant demand of up to 75 percent. With the MIEX® DOC process, the primary function of the downstream coagulation process is turbidity control.

Extensive laboratory studies by the Australian Water Quality Centre (AWQC) have demonstrated that with MIEX® treated water from a wide variety of sources, alum doses of less than 20 mg/L are sufficient to obtain an acceptable treated water turbidity. At these relatively low doses, direct filtration may become a viable option. In direct filtration, the coagulant is rapid mixed with the MIEX® treated water and applied directly to the filters. If a tank is provided for extended flocculation time, the process is termed contact filtration. Direct filtration is normally practiced with waters of very low turbidity (< 10 NTU) and generally low DOC.

The proposed Mount Pleasant water treatment plant in the Adelaide Hills will incorporate MIEX® treatment technology. The designated water source is the River Murray, via the Mannum-Adelaide pipeline. The water quality is generally poor, with turbidity averaging 55 NTU (5 year average) with frequent spikes above 150 NTU. With the highly turbid nature of this water, direct filtration becomes a significant challenge as studies have shown that direct filtration is feasible only when low coagulant doses (< 20 mg/L) are applied.

Laboratory scale simulations of the direct filtration process demonstrated that its application to MIEX® treated River Murray water may be feasible. The purpose of this study was to assess whether MIEX® pretreatment of River Murray water would allow successful application of alum in direct filtration mode on a pilot scale. Acceptable operation was defined as achieving the product water turbidity goal of 0.3 NTU or less. Other coagulants including several polymers were also examined.

Three filter columns containing different filter media were set up at the MIEX® pilot plant (capacity 160 kL/day). Two operate with dual-media filters, while a third is a deep coarse sand filter. Pilot testing showed that one of the dual-media filters (750 mm 1.1 mm anthracite over 300 mm sand) gave the best results. Alum was shown to work effectively

at low doses (< 20 mg/L) when the MIEX® treated water was pH adjusted to 6.0 after alum addition. At the lower temperatures applicable at this time (13°C), it was necessary to correct pH to ensure rapid floc formation with the design constraints applicable at the pilot plant. This may not be necessary at higher temperatures or with increased time between alum addition and filtration. PolyDADMAC LT-35, a cationic polymer, worked well under all conditions, with doses less than 2 mg/L most effective. LT-22, an anionic polymer was tested as a coagulant aid, while polyaluminium chloride (PACl) was tested as a primary coagulant. Neither LT-22 or PACl performed as well as LT-35.

KEYWORDS

MIEX®, direct filtration, River Murray, alum coagulation, polymer.

INTRODUCTION

The MIEX® DOC process (a registered trademark of Orica Australia Pty. Ltd.) has the ability to remove a significant fraction of the natural organic matter (NOM) present in drinking water supplies. Some of the benefits of this technology that have been identified include lower disinfection by-product formation and reduced coagulant demand. For example, at the Hope Valley Treatment Plant (Adelaide, SA), the MIEX® DOC pilot plant achieved a 70 percent reduction in the downstream alum dose required for turbidity control compared with alum dosing of the raw water in conventional treatment operation (Morran *et al*., 1996). Similar results were obtained for a pilot plant located at the Wanneroo Groundwater Treatment Plant (Perth, WA) (Bourke *et al*., 1999). The advantage of this is a reduction in treatment chemical costs and a subsequent reduction in waste sludge handling and disposal costs. The MIEX® resin removed a significant fraction of the dissolved organic carbon (DOC) that would react with the alum coagulant, thereby reducing the organic coagulant demand. With the MIEX® DOC process, the primary function of the downstream coagulant addition is turbidity control.

In contrast to conventional treatment, the practice of direct filtration (DF) has primarily been limited to low turbidity waters. Key advantages of DF include reduced capital and operating costs. Based on pilot-scale and full-scale studies, Janssen *et al*. (1986) found that DF was suitable for waters with turbidity less than 10 NTU. Vigneswaran *et al*. (1983) proposed that DF not be used when peak turbidity exceeded 25 NTU. Hutchison (1976) suggested an upper limit of 12-15 mg/L alum for direct filtration. Logsdon *et al*. (1993) performed DF pilot-scale testing on a turbid water source (20-28 NTU) that experienced episodes of naturally high turbidity (up to 59 NTU). Optimisation of the coagulant dose and to a greater extent the polymer dose was found to be critical in producing low turbidity product water. The alum dose was 7 mg/L, with 0.26 mg/L cationic polymer and 0.01 mg/L non-ionic polymer. The system was found to operate successfully when a deep sand filter was used; a shallower dual-media filter was not acceptable.

SA Water commissioned a small MIEX® pilot plant to obtain detailed design parameters for construction of a full-scale plant at Mount Pleasant in the Adelaide Hills. In particular, assess the feasibility of coupling MIEX® treatment with DF and identify the necessary filter media configuration. Membrane filtration following MIEX® treatment was also examined, but is not discussed in this paper. The plant was located at Murray Bridge, 90 kilometres east of Adelaide, and operated with raw River Murray water. Based on the reduced alum coagulant demand associated with MIEX® pretreatment, a study was initiated to assess the feasibility of using direct filtration with MIEX® treated River Murray water.

MATERIALS AND METHODS

Laboratory jar tests were performed with MIEX® treated water from the pilot plant in 2 L plastic jars. Either alum ($Al_2(SO_4)_3.18H_2O$) or polyDADMAC LT-35 (a cationic polymer) were dosed and rapid mixed for 1 minute, followed by either filtration through Whatman No. 1 filter paper (to simulate direct filtration), or five minutes of flocculation at 20 rpm followed by filtration (to simulate contact filtration). Jar tests simulating conventional treatment (coagulation, flocculation, sedimentation and filtration) of raw water and laboratory batch MIEX® treated water were also conducted.

Three filter column media configurations were selected for pilot plant testing and are summarised in Table 1.

Table 1 Filter media configurations used in MIEX® / direct filtration study

Column	1	2	3
Filter Type	Dual Media	Dual Media	Deep Monomedium
Sand Depth (mm)	280	280	1550
Anthracite Depth (mm)	450	700	-
Gravel (mm)	300	300	300
Sand ES # (mm)	0.5	0.5	1.5
Anthracite ES (mm)	1.1	1.1	-
Sand UC ##	1.45	1.45	n/a
Anthracite UC	1.34	1.34	-

Effective Size (ES): size at which 10 percent (by mass) of the particles are smaller.
Uniformity Coefficient (UC): ratio of the 60% passing size to the ES (measure of size variation).

Columns 1 and 3 are representative of those used at Hope Valley and Happy Valley water treatment plants in metropolitan Adelaide, while column 2 is representative of that used at Morgan water treatment plant in the Riverland. These configurations were selected because of anticipation of retro-fitting the MIEX® technology into existing plants, which would be cheaper than building new facilities. The column diameter was 20 cm. Two separate dosing units were set up for alum and polymer. Polymers tested included polyDADMAC LT-35 (Ciba Speciality Chemicals Australia, NSW), LT-22 (an anionic polymer used as a coagulant aid at several Adelaide water treatment plants) and polyaluminium chloride (Hardman Australia, NSW). Coagulant metering was controlled with two solenoid dosing pumps (Prominent® beta BT4a, All Pumps, SA). Filtration rates of 4-9 m/hr were tested. The turbidity of column filtrate samples was analysed using a ratio turbidimeter (Model 18900-700, Hach Chemical Company, USA). Transient pressure drop profiles were also recorded. The filter feed water turbidity was consistently 55-60 NTU, the pH was 7.8 and the DOC varied from 2.6-3.8 mg/L during the filtration trials, corresponding to 40-50 percent DOC removal with the MIEX® pretreatment stage.

RESULTS AND DISCUSSION

Table 2 summarises the laboratory jar testing results on raw and batch MIEX® treated river Murray water. These jar tests simulated conventional water treatment. A 74 percent reduction in DOC was obtained with a resin dose of 6 mL/L and 30 minutes contact time. Although only 20 mg/L alum was required to obtain the desired filtered water turbidity of 0.3 NTU with the raw water, less than 10 mg/L was necessary for the MIEX® treated water; a reduction in alum dose of at least 50 percent. The low alum requirement for the raw water is possibly associated with the nature of the organic material at the time of sampling (January 2000).

To more closely examine direct filtration, jar tests were performed on MIEX® treated water from the pilot plant, using a flocculation time of either 0 or 5 minutes (Table 3). In both cases, an alum dose of approximately 10 mg/L was required to meet the 0.3 NTU turbidity goal, with 0.2-0.5 mg/L LT-35 providing even better turbidity removals. Thus, the use of low coagulant doses with turbid River Murray water appeared feasible.

Table 2 Turbidity and DOC removal results before and after MIEX® treatment (conventional treatment simulation)

Raw River Murray Water				MIEX® Treated Water #		
Alum Dose (mg/L)	DOC (mg/L)	Turbidity (NTU)		DOC (mg/L)	Turbidity (NTU)	
		Unfiltered	Filtered		Unfiltered	Filtered
0	5.0	62		1.3	54	
10				1.3	1.3	0.15
20	3.8	2.5	0.3	1.3	1.4	0.13
30				1.3	1.5	0.11
40	3.3	3.8	0.2	1.3	1.4	0.09
60	2.8	2.2	0.1	1.3	1.6	0.08

Resin dose = 6 mL/L

Table 3 Jar test results with MIEX® treated water (MIEX® resin dose = 8 mL/L) (direct filtration and contact filtration simulations)

	Dose (mg/L)		Turbidity (NTU)	
Flocculation time (min)	Alum	PolyDADMAC LT-35	Initial	Final
0	5	0	48.3	3.37
“	10	0	“	0.23
“	0	0.2	“	0.28
“	0	0.5	“	0.18
“	0	1.0	“	0.10
5	5	0	45.4	2.71
“	10	0	“	0.30
“	0	0.2	“	0.30
“	0	0.5	“	0.28
“	0	1.0	“	0.13

Figure 1 shows the effluent turbidity profiles for various alum doses with column 3 (deep sand filter). A low filtration rate of 4.5-5 m/hr was initially used to identify suitable coagulants and doses. Visible pinpoint floc formation was observed in the column water head. For a wide range of alum doses (13-85 mg/L), the effluent turbidity goal of 0.3 NTU could not be attained. Increasing the dose yielded a visibly higher concentration of floc in the water head above the filter column and resulted in a lower initial turbidity and faster ripening (defined as the time period between start-up and when the filter effluent goal is achieved). However, with alum doses above 38.5 mg/L, the time that low turbidity could be sustained decreased with increasing alum dose. A possible explanation is that with increasing alum dose the coagulation reaction rate increases, resulting in larger floc that may be more easily sheared within the column, yielding small particles amenable to filter penetration through the relatively large voids in the coarse sand filter.

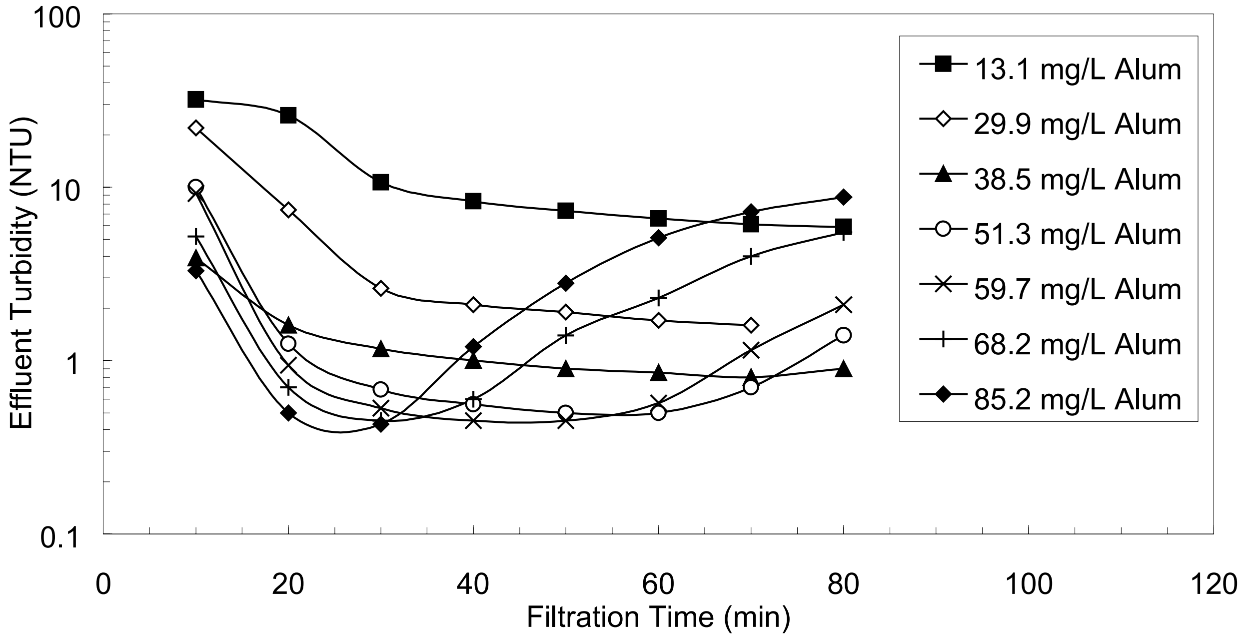

Figure 1 Effluent turbidity profiles for the deep sand filter (column 3)

The filter performance at two different LT-35 polymer doses is shown in Figure 2. At a dose of 2 mg/L a higher concentration of floc was observed in the column water head than with alum, indicating improved floc formation with LT-35. However, the 0.3 NTU turbidity goal was not reached after 100 minutes and the test was halted. It was concluded that the deep coarse sand filter would not be suitable for direct filtration. The higher polymer dose of 5 mg/L deleteriously impacted filter performance. Very little floc formation was observed in the filter, indicative of particle restabilisation.

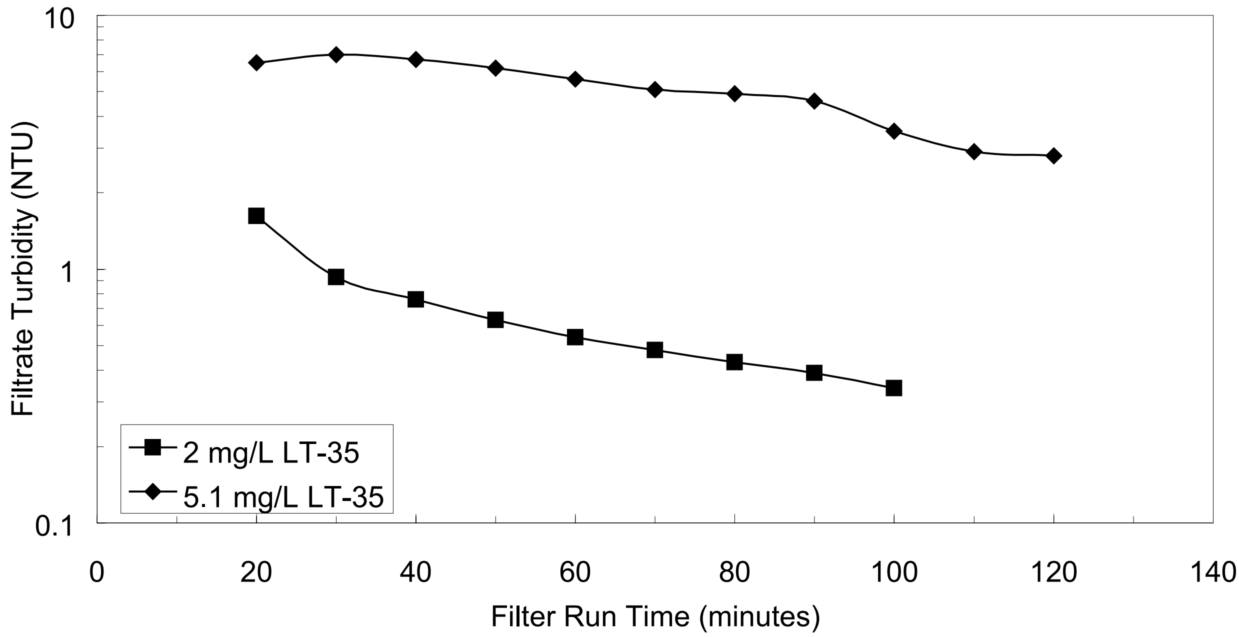

Figure 2 Performance of LT-35 with the deep coarse sand filter (column 3)

Figure 3 illustrates the results obtained with column 1 (dual-media filter). An alum dose of 65 mg/L was required to reach the 0.3 NTU goal, which could not be achieved with the deep sand filter. However, this could only be sustained for approximately 90 minutes prior to turbidity breakthrough. No significant increase in pressure drop across the filter was observed, indicating that turbidity breakthrough was the limiting factor.

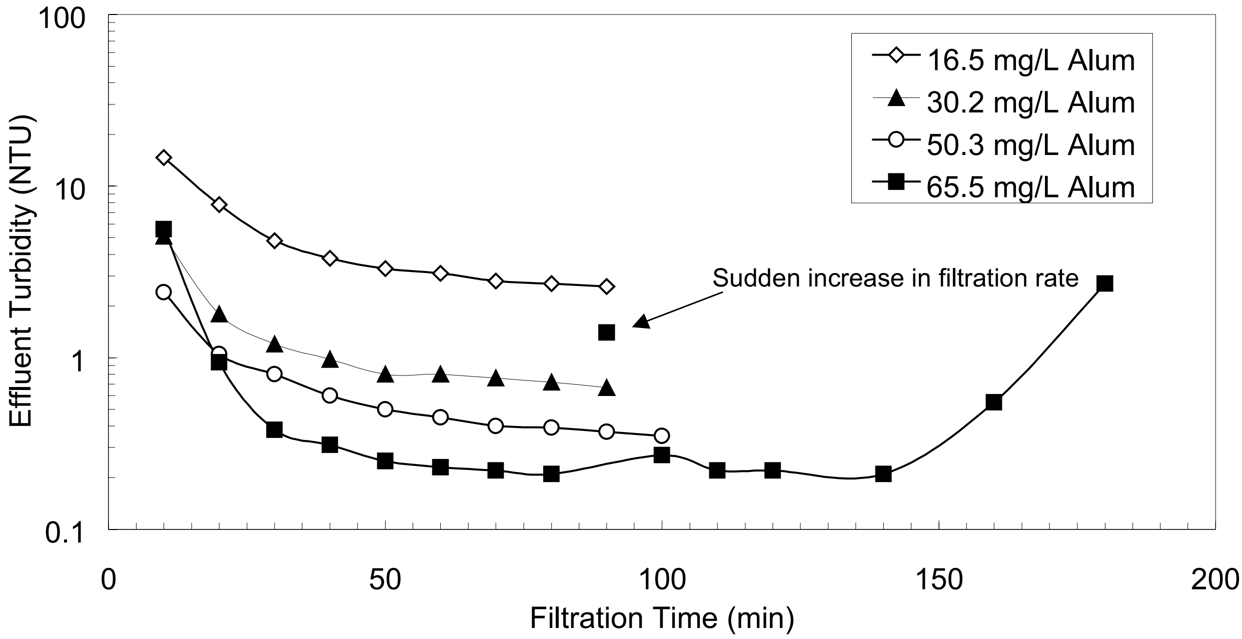

Figure 3 Effluent turbidity profiles with dual media filter (column 1)

Table 4 summarises the results of additional filter runs performed with alum and various polymers. Ripening time is defined as the time required from the start of a run to achieve the filtered water turbidity goal (0.3 NTU). Generally, if this was not achieved within 2 hours of commencing a run then the test was halted and a production time of zero hours was recorded. The production time is defined as the time that water of turbidity less than 0.3 NTU was produced prior to turbidity breakthrough. LT-35 was found to yield short ripening times (30-40 minutes) and excellent filter production times at both low (4.5 m/hr) and moderate (9 m/hr) filtration rates with the dual-media filters, with column 2 displaying the best performance due to the deeper anthracite bed. Although not shown, the filter pressure profiles showed excellent penetration of the floc through the anthracite layer; good utilisation of the void volume in the anthracite bed. Testing of alum with LT-22 as a coagulant aid did yield production times in the order of 4-6 hours, but high LT-22 doses were required (typical doses in practice are less than 0.1 mg/L) and very long ripening times (2-4 hours) were required.

In the jar tests, 10 mg/L alum yielded good floc formation. However, in the pilot plant, no floc formation was visible in the filter column water head, even at higher alum doses of 20-30 mg/L. A possible explanation is the relatively cold water temperature at the pilot plant (13-15^{o}C) versus 23-25^{o}C used in the jar tests. The rate of alum hydrolysis to form the required polynuclear hydroxo complexes for effective coagulation may have been too slow. To test this hypothesis, polyaluminium chloride (PACl) was also tested at an equivalent alum dose of 21 mg/L. In Table 4, PACl coagulation was more effective than with alum. A ripening time of 1 hour and a production time of 3.5 hours was achieved, but was still less effective than LT-35.

Other than temperature, pH is also an important parameter. pH controls both the kinetics and nature of the coagulation mechanism. The pH of the MIEX® treated water after alum dosing was in the range of 7.3-7.6. Laboratory jar tests showed faster floc formation, as well as lower filtered turbidity at low alum doses (20 mg/L), when the pH was adjusted to 6.0 after alum addition. Based on these results, a filter run with column 2 (dual-media) was performed using an alum dose of approximately 20 mg/L. The alum stock solution was spiked with concentrated hydrochloric acid such that at an alum dose of 20 mg/L the target pH of 6.0 would be attained. The product water turbidity and pH profiles are shown in Figure 4. The water temperature was 13^{o}C and a filtration rate of 4.3 m/hr was used.

Table 4 Summary of direct filtration trial results

Column	Water Temp. (^{o}C)	Filtration Rate (m/hr)	Alum Dose (mg/L)	LT-35 Dose (mg/L)	LT-22 Dose (mg/L)	PACl Dose (mg/L as alum)	Ripening Time (min)	Production Time (hrs)
3	15.4	4.9	-	2.0	-	-	-	0
3	14.6	4.6	-	5.1	-	-	-	0
1		4.3	-	2.3	-	-	-	0
1		4.1	-	6.0	-	-	-	0
1		4.3	21.7	2.2	-	-	-	0
1	13.5	4.6	-	1.2	-	-	110	> 10 #
1	13.6	8.9	-	1.0	-	-	40	5
2	13.7	9	-	0.9	-	-	30	8
2	13.1	4.7	21.7	-	0.00-0.17	-	240	4
2	12.7	4.6	21.8	-	0.35	-	120	> 6 #
2	12.9	4.7	-	-	-	21.3	60	3.5

Run stopped because of no available night operation staff.

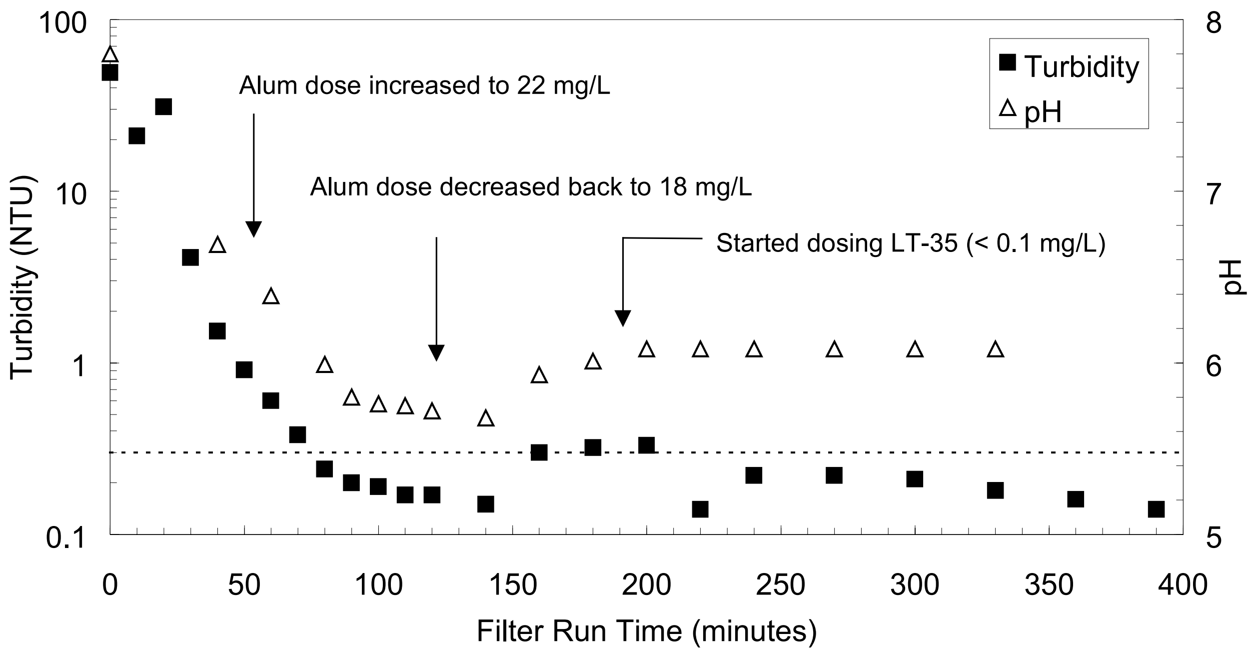

Figure 4 Effluent turbidity and pH profiles for column 2 (alum coagulation with pH adjustment)

Greatly improved filter performance was attained compared with earlier tests. A ripening time of 80 minutes was required to meet the 0.3 NTU finished water turbidity goal. At 45 minutes the alum dose was increased slightly because the pH was not near the target pH of 6.0. The pH stabilised at 6.1, corresponding to an alum dose of 18 mg/L. PolyDADMAC LT-35 was dosed at less than 0.1 mg/L as a coagulant aid after three hours to assist maintenance of low turbidity. Residual aluminium was less than 0.06 mg/L, well below the Australian drinking water guideline level of 0.2 mg/L. The product water turbidity decreased to less than 0.2 NTU with increasing run time. Although the filter run was halted after 390 minutes it was anticipated that sustained water production well in excess of 10 hours could be achieved.

Direct filtration with pH adjustment confirmed that pH can negate the adverse effect of low water temperature on alum coagulation kinetics. The test also confirmed the feasibility of direct filtration of MIEX® treated River Murray water of high turbidity (55-60 NTU) with low alum doses. It is important to emphasise that because of the limited duration of this study other media configurations and longer contact times before filtration may also be a solution, rather than pH adjustment.

CONCLUSIONS

Direct filtration of MIEX® treated river Murray water with an average turbidity of 55 NTU is feasible. A dual-media filter consisting of 280 mm sand (0.5 mm ES) and 700 mm anthracite (1.1 mm ES) was identified as the best filter medium. The low water temperatures (< 15^{o}C) during the pilot trials clearly slowed down the kinetics of alum floc formation, resulting in the filtered water turbidity goal of 0.3 NTU not being achieved. Adjusting the pH to 6.0 was found to greatly increase the rate of floc formation and resulted in excellent filtration performance (ie. turbidity < 0.3 NTU and good floc penetration into the anthracite bed). Unlike alum, the cationic polymer polyDADMAC LT-35 was not affected by the cold water temperature and was very effective at low doses (2 mg/L) without pH adjustment.

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