BIOLOGICAL MANGANESE REMOVAL – A VERY SUSTAINABLE WATER TREATMENT TECHNOLOGY

Paper Presented by:

Peter Baudish

Author:

Peter Baudish, *Water Treatment Practice Leader,*

Sinclair Knight Merz

4th Annual WIOA NSW Water Industry Engineers & Operators Conference
St Stanislaus' College, Bathurst
20 to 22 April, 2010

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ABSTRACT

The presence of manganese often results in consumer complaints associated with black particulates that cause staining and generally lowers public perception of water quality.
Waimakariri District Council (NZ) encountered such problems when a new source was developed for the Woodend Water Supply. A biological filter was chosen in preference to conventional physico-chemical treatment processes that have been traditionally used for manganese removal.

This paper provides a summary of the processes undertaken in developing and implementing an operational biological filter that has very high manganese removal efficiencies, uses no chemicals and has a lower capital and operational cost than conventional removal processes. Performance characteristics and operational issues of the filter are presented and discussed.

KEY WORDS

Water Treatment, Manganese, Iron, Biological Manganese Removal

1.0 INTRODUCTION

Woodend is a small town of about 2500 population located in the Waimakariri district, Canterbury, NZ. Chinnerys Road bores were the original source for Woodend . This source has elevated iron concentrations averaging 0.54 mg/L, and is in terms of the New Zealand Drinking Water Guidelines is a (microbiologically) unsecure source. Iron was removed by aeration and filtration, with disinfection also required.

The Gladstone Park well was commissioned in 1999 to replace the Chinnerys Road bores. It is 200m deep and is a (microbiologically) secure source. As such it required no specific treatment for pathogen removal. It was an untreated groundwater supply, without filtration or disinfection. The supply has a manganese concentrations of approximately 0.05 mg/L.

After approximately two years of trouble free operation of the Gladstone Park well, black particulate material started appearing in the supply system, resulting in the staining of clothing and raising significant concern among consumers. This resulted in numerous complaints being made to the Waimakariri District Council (WDC) and reduced public confidence in the supply.

A review of possible treatment process options identified chemical oxidation, catalytic oxidation and various hybrids of these processes followed by, or in conjunction with, filtration as the conventional approaches available. Biological filtration was also identified as a possible treatment technology. The potential for a chemical free option was of considerable interest to the Woodend community as there was reluctance to introduce chemicals to their high quality chemical free water supply. Biological treatment was selected for trialling in parallel with conventional catalytic treatment for comparison. Though the latter is not discussed here, it performed to expectations.

2.0 DISCUSSION

2.1 Characteristics of Iron and Manganese Bacterial Growth

Bacteria living in environments where there is no light require an alternative energy source to achieve growth. Iron and manganese bacteria that occur naturally in groundwater have specifically evolved to make use of the small amounts of energy released when oxygen reacts with soluble un-oxidised manganese or iron (Mn^{2+} or Fe^{2+}). The energy is used by the bacteria to assimilate carbon dioxide, achieving biological growth with the iron (or manganese) accumulating around bacterial cells and being incorporated into bacterial sheaths.

The bacterial biomass formed is dense and robust compared to chemical floc or chemically oxidised forms of iron and manganese ($Fe(OH)_3$ and MnO_2). Filtration rates of over 30m/hr are achievable. The rate of head loss build-up is also relatively slow (because of the dense nature of the biomass) resulting in long filter run lengths. Variables that influence the biological activity include redox potential (Eh), dissolved oxygen (DO) concentration, manganese concentration, pH and temperature, (Ref1), and simplified in Table 1.

Table 1: ***Indicative parameters for biological manganese and iron removal and source water quality***

	Optimum Parameters for Biological Removal		Typical Water Quality of Sources	
Parameter	Manganese	Iron	Gladstone Park	Chinnerys Road
Dissolved oxygen	>5 mg/L	0.2 – 0.5 mg/L	1.6 – 2.1 mg/L	6.4 – 9.0 mg/L
pH	7 to 8.5	6 to7	6.9 – 7.3	6.4 – 6.8
Redox potential	400 to 600 mV	0 to 200 mV	-10 to -60 mV	10 to 50 mV
Hydrogen sulphide	<0.01	<0.01	Nil	Nil
Iron			0.04 mg/L	0.54 mg/L
Manganese			0.049 mg/L	0.004 mg/L

In respect of the Gladstone Park source, the pH was just in the range for manganese removal, while DO was too low without supplementary aeration. The redox potential also appeared on the low side. While these factors were given due consideration, field observations that biological manganese removal was occurring naturally within the reticulation system was evidence that the process had potential, especially since the addition of aeration upstream of the existing filter could be easily achieved and might be the only extra process requirement.

2.2 Pilot Trials

Pilot trials were undertaken in five stages with the broad objective of developing an understanding of the treatment performance characteristics of biological filtration compared to conventional treatment processes.

Stage I Objective – establish colonies of manganese bacteria in the trial filter and assess the effectiveness of the biological manganese treatment for the Gladstone Park source: Water from the Woodend reticulation was passed through the filter continuously without backwashing for a period of six weeks.

Bacterial colonies established rapidly (within 3 to 4 weeks), with excellent manganese removal being achieved as shown in Figure 4. Iron removal also improved during the seeding period, though the incoming iron was already at low levels. Figure 5 shows the presence of dark biomass in the filter backwash water.

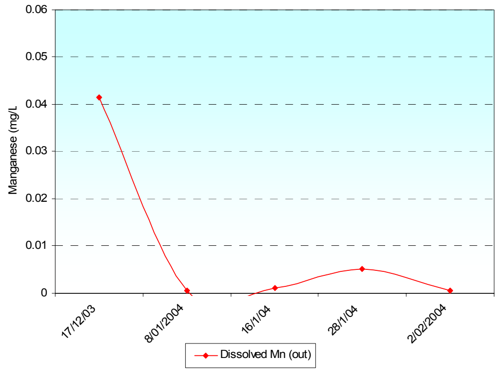

Figure 4: ***Manganese Removal, Stage I*** **Figure 5:** ***Backwash Discharge***

Stage II Objective – Identify backwashing frequency and flow rates required to clean the filter and their impact on manganese removal efficiency: The filter was operated for approximately three weeks, and backwashed every 5-7 days. Sampling showed that the DO levels in the filtered water was above 5 mg/L and manganese was removed from the incoming level of 0.050mg/L to levels generally below the detection limit of 0.005 mg/L. In spite of the more frequent backwashing biological activity was maintained.

Stage III Objective – Assess filter performance when the supply was switched from the Gladstone Park to the high iron / low manganese Chinnerys Rd Source for a short period of time: The trial was run for a period of approximately 2-weeks to mimic what would happen if a switch to Council's backup source was required A high degree of iron removal occurred immediately, with the iron levels dropping from an incoming 0.54mg/L to below the detection limit of 0.02 mg/L in the filter outlet within three hours of switchover. However there was some evidence of manganese "bleed" from the biofilter.

Stage IV Objective – Assess re-establishment of manganese removal on change back to the Gladstone Park source: The biological filter quickly adapted to the new conditions, with manganese removal to below the detection limit achieved within one day of switchover.

Stage V Objective – Media trials. Three media designs were trialled. A 40% higher flow rate was observed for the 1.0 - 1.4mm sand compared to the 0.8- 1.2mm sand and 1.0 - 1.4mm sand-garnet dual media. Manganese removal was equally good.

The pilot trials showed that biological filtration was extremely effective at removing manganese and iron, and was able to treat both Gladstone Park and Chinnerys Road sources effectively with no change in filter set-up. In spite of a number of uncertainties, the trials gave sufficient confidence to proceed with modifications of the existing AVG filter the full-scale filter, This was endorsed by the Council and Woodend Residents Association.

2.3 Full Scale Trial Results

Converting the existing AVG filter to a biological manganese filter required several modifications including repairs to the existing structure and piping, replacement of sand media, construction of backwash tanks and a disposal system to sewer as well as the addition of an air injection system to the raw water supply.

The filter performance for the period April 2005 to June 2006 is summarised in Figure 6.

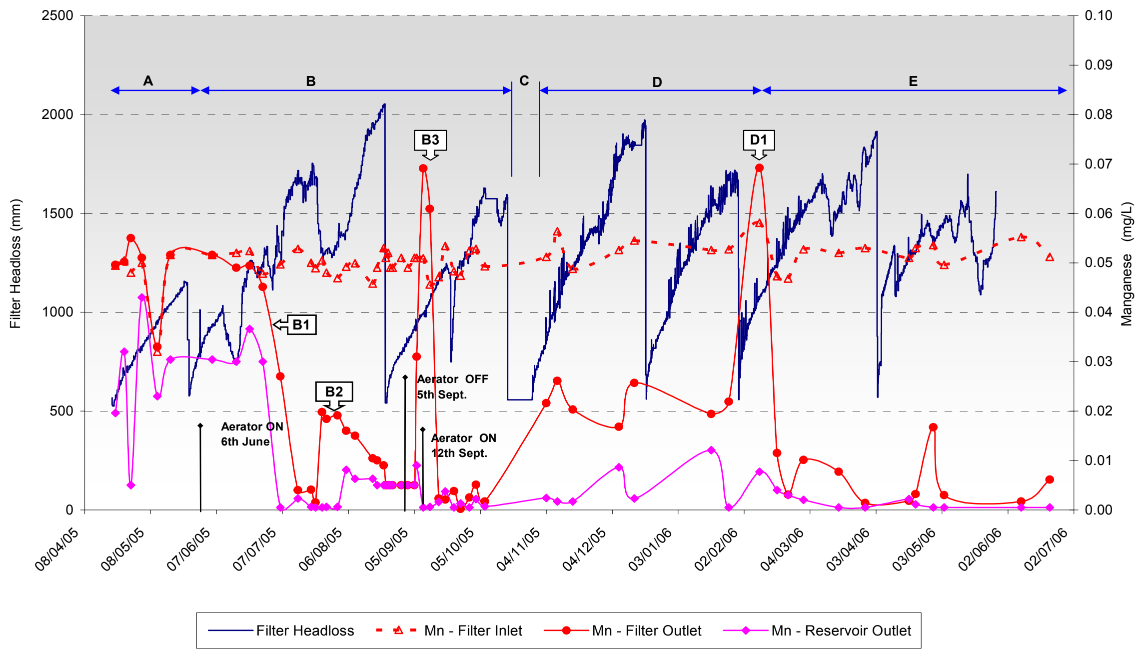

Figure 6: ***14 Months of full scale operations of biological filter***

Over the 14 months of operation there were about seven backwashes with the Gladstone Park source, represented by the steep vertical drop in the head loss curve. For the most part, the rising head loss curves of the AVG filter are somewhat jagged, reflecting the intermittent operation of the filter as it starts and stops several times throughout the day. There are also some unexplained changes in the head loss trends where there may have been a partial automatic backwash, possibly caused by the introduction of air into the filter. These anomalies have not been investigated, as they did not appear to have significant impact on the manganese removal efficiency of the filter.

The graph presented in Figure 4 has been broken into five time periods A, B, C, D, and E and the performance of the filter during these discrete periods is discussed in the following sections.

Period A: For the first month the AVG filter was operated without an aerator. Though clearly no removal of manganese was taking place as (the post filter manganese was identical to the incoming manganese) there was head loss accumulation in the AVG filter. When the filter was backwashed, the colour of the backwash water was a very rusty colour. It appeared therefore that the very low levels of iron (0.05 mg/L) were being completely removed.

Period B: An aerator unit was installed, commissioned and then operated for three months from June 6 to September 5, 2005. After only four weeks the filtered manganese level was below 0.01 mg/L where it remained for three weeks. The manganese then hovered between 0.01 and 0.02 mg/L (B2) for a month and then dropped below 0.0005 mg/L, the manganese detection limit.

At the end of this phase the aerator was turned off. Manganese levels immediately spiked upwards within a day (B3). After a week the aerator was turned on and manganese levels immediately returned to below 0.01 mg/L.

Period C: The AVG filter was switched to the Chinnerys Rd source for a period of 10 days 18 to 27 October 2005 (Figure 7).

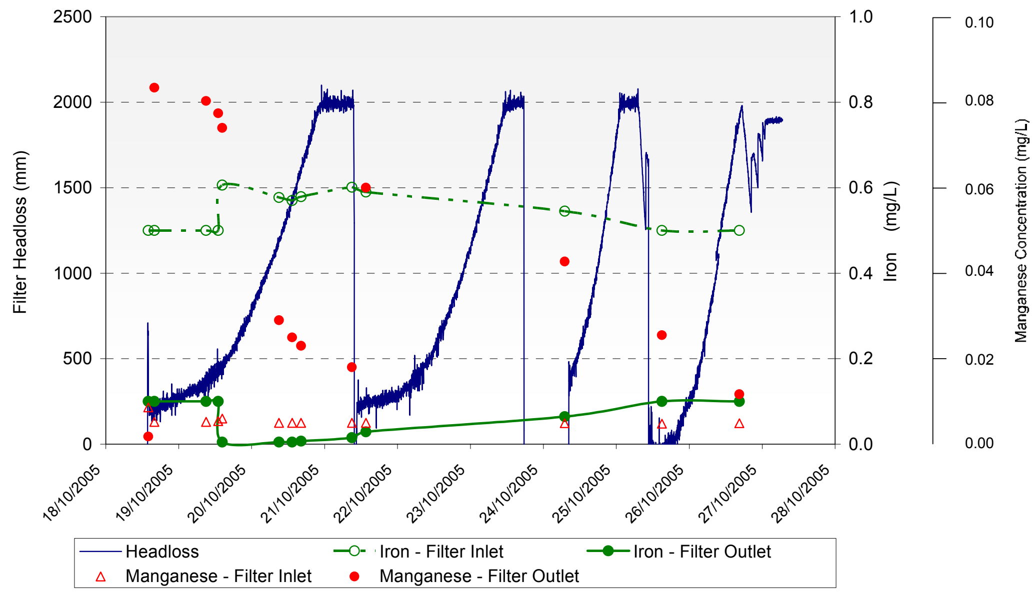

Figure 7: ***Chinnerys Rd – Iron removal and head loss characteristics***

In contrast to a backwash cycle of the order of two months for the Gladstone Park source, backwashing was required every two to three days with the Chinnerys Rd supply. As with the pilot trials bleed of manganese was observed.

Period D: After reverting from Chinnery's Rd to the Gladstone Park source the filter performance did not "recover", with post filter manganese levels remaining around 0.02-0.025 mg/L. This was not investigated immediately as manganese levels exiting the service reservoir remained low. In about mid February 2006 dissolved oxygen levels were checked and found to be relatively low due to a malfunctioning blower. The very high spike (D1) occurred when the aerator was completely removed for repair.

Period E: Since repair of the aerator in February 2006, and now with four year of operation manganese levels have consistently averaged under 0.01 mg/L, while the water exiting the service reservoir has been usually non detectable.

3.0 CONCLUSIONS

- Manganese bacteria are adaptable and appear to be able to effectively remove manganese under raw water quality conditions outside of the optimum range reported in the literature.
- A full scale biological filter is very cost effective and requires no chemicals.
- Biological manganese removal pilot scale trials are effective for predicting the performance of a full scale plant.
- The Woodend filter was capable of operating for over two months without backwashing when treating the Gladstone Park water in biological manganese removal mode.
- The biological filtration process is very robust, and is capable of coping with frequent starting and stopping of supply of the filter operations as well as short term treatment of the Woodend's emergency source – the iron rich Chinnerys Rd well - though some manganese "bleed" was observed when operating in this mode.
- Following the introduction of a manganese removal process there may be a delayed but short term increase in dirty water complaints. This is probably due to the biofilms of manganese bacteria that live on reticulation pipe walls being starved of their energy source, then dying and sloughing off.

Overall both the pilot trials and full scale operations confirmed the feasibility of biological manganese treatment at Woodend with high manganese removal efficiencies possible on the Gladstone Park source. The process was extremely efficient at removing manganese, with the average filtered water manganese levels achieved being under 0.010mg/L.

4.0 ACKNOWLEDGEMENTS

This paper is based on "Biological Removal of Manganese in a Community Water Supply" by Matthew Sheppard and Peter Baudish of SKM, and Gary Boot of Waimakamri Council. That paper contains further details of the investigations and pilot trials that led to implementation of the full scale system

5.0 REFERENCES

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