BIOLOGICAL ACTIVATED CARBON (BAC) REMOVAL OF SOLUBLE MANGANESE FROM DRINKING WATER

Jarad Shorthouse, *Process Engineer,* Beca HunterH2O

ABSTRACT

This project assessed the performance of a biological activated carbon (BAC) filter in removing soluble manganese from drinking water. Findings from this experiment aimed to provide evidence for BAC filtration as a new method that addresses existing issues of removing soluble manganese during the water treatment process.

Experimental work involved studying BAC filter soluble manganese removal performance when introduced to feed water with a range of manganese concentrations from 0.2 to 2 mg/L to determine the upper limit for the filter. A second filter column with sand as the filter media was run under the same conditions to compare the performance with that of the BAC filter. This work was conducted on a benchtop-scale and the experimental period lasted a total of 6 weeks.

The results showed significantly high soluble manganese removal for the BAC filter of up to 99% reduction in manganese concentration in the filtered water compared to that in the feed water. The BAC filter's soluble manganese removal was significantly greater than the median 4% removal rate of the sand filter. This suggests that BAC filter media could become an effective replacement to traditional types of filter media.

1.0 INTRODUCTION

Manganese (Mn) is found naturally in drinking water supply sources from both surface water and groundwater. At high concentrations, manganese can cause brown or black water that can stain plumbing fixtures, basins, and clothes, as well as induce corrosion in water distribution systems.

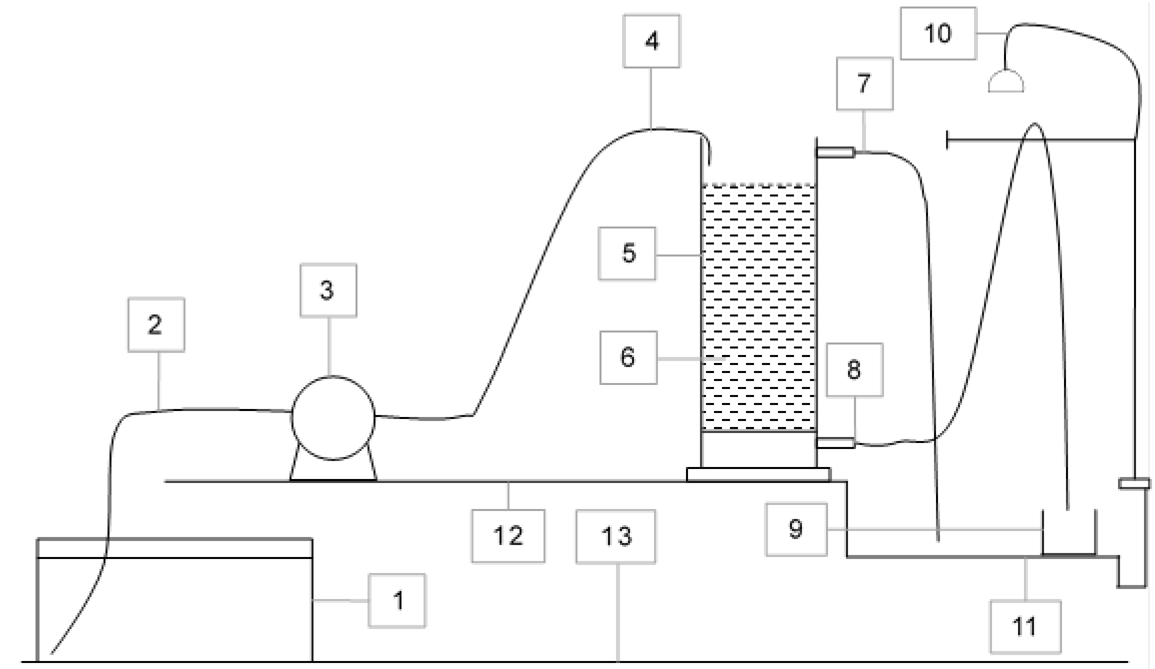
Precipitated manganese in particulate form (Mn^{4+}) is readily removed by common water treatment processes utilising filtration; however, soluble manganese (Mn^{2+}) is much more difficult to remove. Chemical oxidation is the most common method for removing soluble manganese in drinking water treatment since Mn^{2+} oxidation by oxygen is very slow at pH below 9 and most drinking water sources exist at a pH between 6 and 8. However, chemical oxidation can be expensive and increases the complexity of the water treatment process.

Studies suggest that stronger biological activity could be cultivated by using granulated activated carbon (GAC) as the filter media to host the manganese oxidising bacteria. GAC carbon particles have a highly defined surface honeycomb structure that can be used to provide protection and allow safe surface sites for bacteria to develop on the filter media. The GAC filter with developed bacteria, referred to as a biological activated carbon (BAC) filter, could be an alternative method for effective manganese removal without the need for aeration and pH pre-treatment that are commonly required with conventional biological filtration. This would be a significant and cost-effective application for drinking water treatment.

2.0 DISCUSSION

2.2 Apparatus

A sketch of the experimental apparatus used for the operation of the filtration columns is shown in Figure 1. For simplicity, the sketch only represents the apparatus associated with one of the two filtration columns. Apparatus involved for the operation of two columns (BAC filter and sand filter) but not shown in Figure 1 includes: one additional filter column with associated inlet, outlet and overflow tubing, one additional feed water tank and one additional pump.



<u>Figure 1:</u> ***Sketch of filtration column apparatus (missing: one feed tank, one pump, one filter column with associated tubing)***

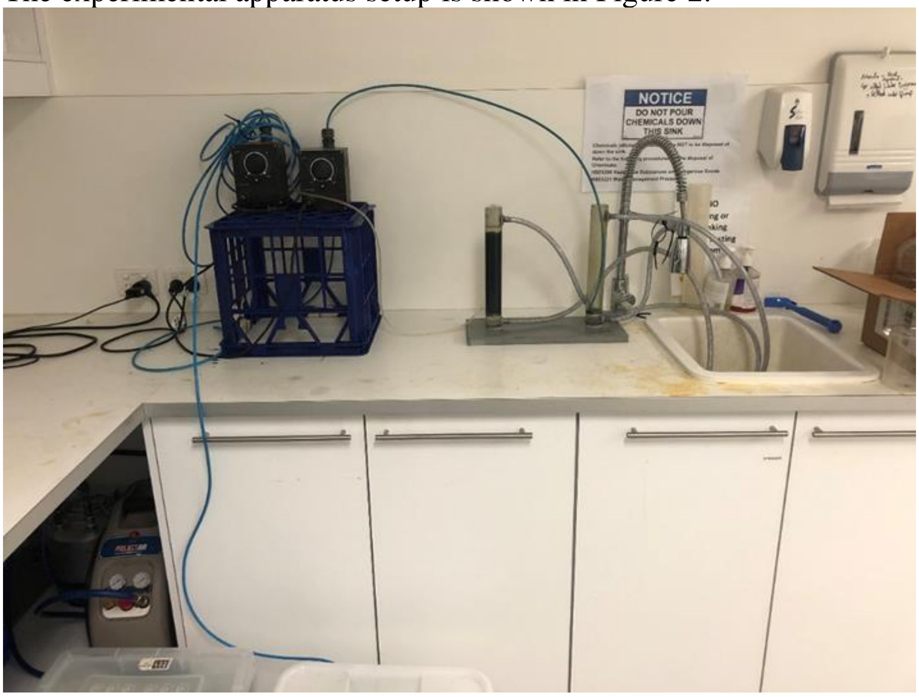
Descriptions of each item of apparatus for the operation of the filtration column in Figure 1 is provided in Table 1.

<u>Table 1:</u> ***<u>Descriptions of filtration column apparatus</u>***

No.	Item	Description
1	Feed tank	Two 50 L plastic storage containers with removable lids held the manganese spiked feed water supply for the columns.
2	Pump suction tube	Plastic tubing approximately 2 mm in diameter connected from the feed tanks to the suction side of the pumps.
3	Pumps	120 L/h Grundfos digital dosing diaphragm pumps used to supply water from the feed tanks to the filtration columns.
4	Inlet tube	Plastic tubing carrying feed water from the discharge side of the pumps to the open top of the filtration columns. The inlet tube was taped to the inside of the filter column.
5	Filtration column	Cylindrical clear PVC columns 300 mm in height and 35 mm internal diameter. Open top column with two 13 mm diameter nozzles (one at the top of the column and one at the bottom) to attach tubing. A fine gauze is installed inside the bottom for holding the filter media.
6	Filter media	The filter media was BAC for one column and sand for the other. The height of the filter media bed was approximately 200 mm.
7	Overflow tube	Plastic tubing approximately 15 mm in diameter connected from the column's top nozzle to the sink. These were used to direct overflowing water

No.	Item	Description
		to the sink in an event of excess headloss buildup.
8	Outlet tube	Plastic tubing approximately 15 mm in diameter connected from the column’s bottom nozzle to the sink or sampling beaker. These were used to carry the filtered water. The filter column’s water level was controlled by adjusting the height of the outlet tube loop.
9	Sampling beaker	500 mL plastic beaker used to collect filtered water samples for analysis. When a sample was not required, the outlet tube would be directed to the sink instead.
10	Sink tap	A horizontal bar extending from the sink tap was used to loop the outlet tube over to provide the height needed for hydraulic level control.
11	Sink	Overflowing water and filter effluent (when filter samples were not required) was directed to the drain in the sink.
12	Benchtop	Testing room bench where the pumps and filtration columns rested on.
13	Testing room floor	Floor of the testing room below the bench where the feed tanks rested on.

The experimental apparatus setup is shown in Figure 2.



<u>Figure 2:</u> ***Experimental setup including feed water tanks (bottom left corner), pumps (top left), and biofilter columns (centre)***

2.3 Methodology

Firstly, the bacteria cultured on the BAC filter required an acclimatisation period of 2 weeks which promoted the growth of manganese-oxidising bacteria and its biofilm on the filter.

Following the acclimatisation period, the BAC filter’s performance was monitored under increasing inlet soluble manganese concentrations whilst other conditions such as temperature, empty bed contact time (EBCT) and pH remained constant. The BAC filter’s performance was measured by testing the filtered water’s manganese concentration and comparing the result to the manganese concentration of the influent to observe the degree of soluble manganese removal. The BAC filter's soluble manganese removal performance was compared to that of a sand filter running adjacently under similar conditions.

The experimental program spanned 6 weeks and is shown in Table 2.

Table 2: *Experimental program*

Testing Period (week)	Manganese (Mn^{2+}) Dose (mg/L)
Acclimatisation period	
1	0.2
2	0.2
Variable inlet Mn^{2+} concentration	
3	0.5
4	1
5	1.5
6	2

2.2 Results

The total manganese concentration in the effluent after filtration through the BAC filter column and sand filter column is comparatively shown in Figure 4. The filtered water manganese concentration is plotted against the total manganese concentration in the influent entering each of the filter columns.

The results obtained from in-house analysis are included along with results obtained from analysis from Sydney Water Labs (SWL) performed on the same samples.

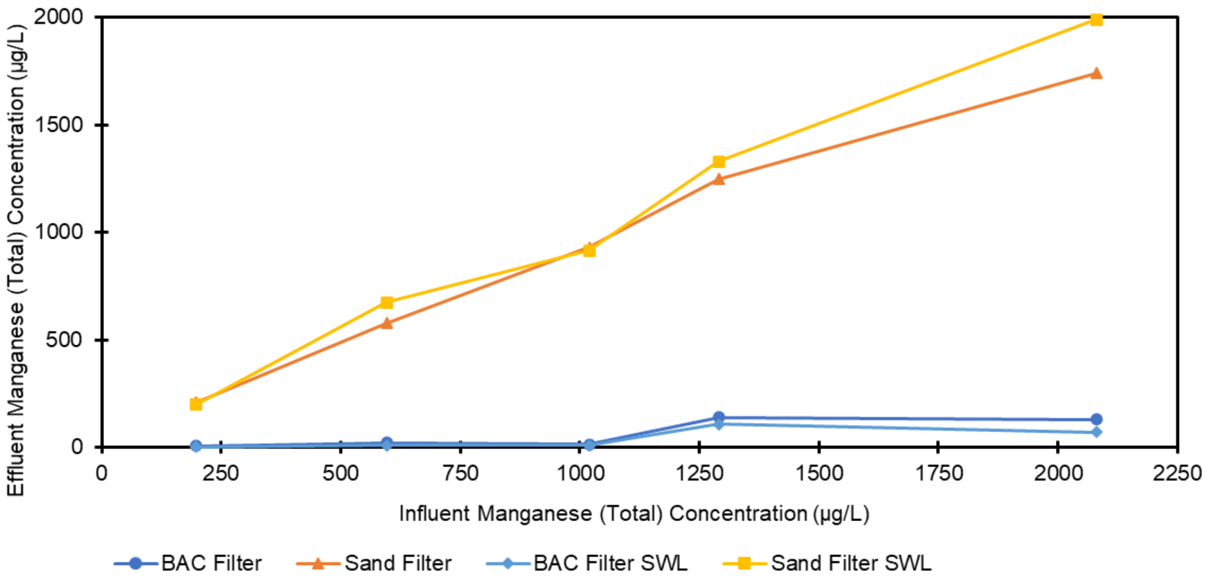


Figure 4: ***Total manganese concentration in the effluent after filtration by BAC filter or sand filter vs total manganese concentration in the influent***

The plotted lines for the in-house analysis and the external lab analysis by Sydney Water Labs (SWL) for both the BAC filter and the sand filter follow the same path with very minimal deviation. Therefore, the similar results from the two different analysis sources provide some justification in the reliability of the manganese concentrations that have been reported.

When comparing the performance of the BAC filter to the performance of the sand filter, the manganese removal of the BAC filter is significantly higher. The sand filter achieved a median manganese removal of 4% across the range of influent manganese concentrations tested. This is shown by the linear line in Figure 4 highlighting that the manganese concentration in the water leaving the sand filter was close to the manganese concentration entering the sand filter. In comparison, the BAC filter achieved a median manganese removal of up to 99%. This suggests that a significant improvement in soluble manganese removal could be achieved if water treatment plants were to switch from sand filters to BAC filters.

A soluble manganese removal rate of 99% is even slightly greater than the literature value of 91% reported in previous studies (Granger et al., 2014). One reason for the higher removal rate is that the manganese-oxidising bacteria preferred the slightly higher pH of around 6.5 compared to the pH of 6 in the study by Granger et al.

The significantly higher soluble manganese removal observed by the BAC filter compared to the sand filter suggests that biological filtration is more effective than physical filtration alone. The biofiltration achieved by the manganese-oxidising bacteria inhabiting the BAC filter is the BAC filter's primary filtration mechanism responsible for the high soluble manganese removal. It is possible that the GAC filter media partly contributed to the removal of soluble manganese through physical filtration. However, it is observed through the performance of the sand filter which has no biological activity and instead relies solely on physical filtration, that biological filtration can achieve up to 95% higher soluble manganese removal.

The BAC filter soluble manganese removal performed effectively to reach the target manganese concentrations set by the Australian Drinking Water Guidelines (ADWG). The BAC filter was able to reduce influent manganese concentrations in the range of 200 – 1000 µg/L to less than 100 µg/L. Where 100 µg/L is the upper aesthetic limit recommended by the ADWG to avoid issues with colour, taste, and staining (NHMRC, 2011). From literature, natural drinking water sources will often only contain up to 600 µg/L meaning that under normal circumstances, these results suggest that BAC filters can achieve soluble manganese removal below the target ADWG aesthetic limit.

However, although far less common, literature reports that the manganese concentration in raw water can reach up to 1410 µg/L in polluted rivers or under anoxic conditions such as at the bottom of deep reservoirs or lakes, or in groundwater. From Figure 4, the manganese concentration of the filtered water begins to increase to higher than 100 µg/L when the influent manganese concentration is higher than 1000 µg/L. However, even when the influent manganese concentration reaches up to 2000 µg/L, the filtered water manganese concentration remains lower than 150 µg/L. This is slightly above the ADWG aesthetic limit but far lower than the target ADWG health limit of 500 µg/L (NHMRC, 2011).

Therefore, with application of BAC filters at a water treatment plant, it can be expected that the manganese concentration of the effluent will remain below the ADWG aesthetic limit under most circumstances and during an event that triggers a significant spike in the raw water manganese concentration, the effluent will safely remain below the ADWG health limit of 500 µg/L.

3.0 CONCLUSION

BAC filtration is an effective method of removing soluble manganese to ADWG standards. Drinking water containing up to 1 mg/L of soluble manganese can be reduced to under the ADWG aesthetic limit of 0.1 mg/L using BAC filtration. Whilst drinking water containing up to 2 mg/L of soluble manganese can be reduced to under the ADWG health limit of 0.5 mg/L.

Literature reports that, under rare circumstances, manganese concentrations can range up to 1.4 mg/L in major Australian reticulated supplies which is considerably lower than the determined upper manganese limit of 2 mg/L for the BAC filter.

Results show that BAC filter media is up to 95% more effective at removing soluble manganese from drinking water than the comparison filter with traditional filter media of sand.

It is proposed that further research work with Hunter H2O in this area is towards assessing the performance of BAC filtration for soluble manganese removal under the effects of additional parameters such as pH, temperature and EBCT. This will provide evidence for assessing the viability of BAC filtration for removing soluble manganese on a larger water treatment scale.

5.0 REFERENCES

Granger, H. C., Park, Y., Stoddart, A. K., & Gagnon, G. A. (2015). Manganese removal by hydrogen peroxide and biofiltration. Journal of Environmental Engineering and Science, 10(4), 81–91. https://doi.org/10.1680/jenes.15.00009

Granger, H. C., Stoddart, A. K., & Gagnon, G. A. (2014). Direct Biofiltration for Manganese Removal from Surface Water. Journal of Environmental Engineering, 140(4), 04014006. https://doi.org/10.1061/(ASCE)EE.1943-7870.0000819

NHMRC. (2011). Australian Drinking Water Guidelines.