ABSTRACT

In our ever expanding world clean unpolluted raw water sources for conventional drinking water treatment plants are becoming scarcer. Furthermore we demand reliable high quality potable water and are constantly looking for more the most sustainable solutions technology can provide. It is a combination of these factors which encourage us to question whether we can do things better.

In municipal treatment plants biological treatment is typically associated with wastewater processes and consequently there are currently no recognised standards for the removal of organics in the production of drinking water, even though this is becoming a more common requirement. The objective of this paper therefore is to analyse the design and performance of the biological removal of organic matter adopted in the Mundaring Water Treatment Plant in Western Australia.

INTRODUCTION

It is well known for decades that the biological activated carbon (BAC) treatment, by adsorption by the activated carbon and biodegradation of bacteria attached on the activated carbon, is one of the most suitable and economical processes for the effective removal of organic contaminants (Nguyen et al., 2013; Jusoh et al., 2011), precursors of disinfection (DBP) (Chu et al., 2012), taste and odour of the water, and therefore we have seen it more commonly being used in recent years.

In many water treatment plants and studies, ozone is used in pre-oxidation prior to biofiltration as without it the biorefractory substances are difficult to remove. Ozonization produces changes in the structures of the humic acids decreasing the UV absorbance and colour of the water due to a loss of aromacity and depolimerization (Camel. V. et al.,1998), increasing the concentration of assimilable organic carbon (AOC), changing the molecular structure to lower molecular weight compounds to more assimilables such oxalic acid, which improves the biodegradation of the organic matter (Chien et al., 2007). Together with activated carbon, conventional treatments such a coagulation, have been used for the removal of organics, as in recent studies by Pramanik et al. (2014) where coagulation and granular activated carbon (GAC) were compared with the performance of the organic removal of the biological activated carbon filters. Organic removal contaminants reclamation has increased over the past years as it has many advantages over the treatments and distribution systems downstream, as it is shown for example in a pilot scale study in Melbourne by F.A. Roddick et al.(2014). A biological activated carbon (BAC) filtration was investigated as a pre-treatment for reducing the organic fouling of a microfiltration membrane demonstrating the potential of BAC pre-treatment for reducing organic fouling and thus allowing a higher sustainable flux for microfiltration. Post chlorination, in even mildly polluted waters unwanted disinfection by products (DBPs) can be generated as a result of natural organic matter (NOM) in the water sources which may form carcinogenic components such as halbacetic acids (HAAs) and trihalomethanes (THMs). The NOM can also allow microorganism regrowth in water supply networks (J.C. Lou et al., 2009 and 2010). Product water from water treatment plants can be chemically complex resulting in physical and biological changes during transportation in the distribution systems before reaching us, the consumers. The regrowth, specially pathogens can have a significant impact on public health. Non-pathogens can also lead to biocorrosion and taste issues, therefore, a focus on the biostability of water and the associated controls are being adopted as they are very useful tools for today's distribution systems.(Chao Chen et al., 2013).

The objective of this paper is to evaluate the effectiveness of “conventional” water treatment plant NOM removal in the Mundaring Water Treatment Plant in Western Australia. The process adopted is based on enhanced coagulation, a combined flotation and enhanced filtration system (DAFF), a Biological Activated Carbon system (BAC), Chloramination and Stabilisation in order to achieve a biologically safe and chemically stable water, with a focus on disinfection by products (DPB) and biostability of the water downstream of the plant, all in accordance with Water Corporation and Australian drinking water Standards.
MATERIALS AND METHODS

Process Units:

**Enhanced Coagulation.** Enhanced coagulation of the raw water is carried out by optimising the pH of the inlet water with CO2. Aluminium sulphate is used as the coagulant with a polyelectrolyte to maximise coagulant effectiveness.

**DAFF.** Dissolved air flotation is combined with a dual media filter comprising sand and expanded clay in a single process unit. The expanded clay provides long filtration times between backwashing, lower backwashing rates, high resistance to blinding by algal blooms and extra DOC removal properties compared with sand and or sand and anthracite, due primarily to its greater surface area. Air for flotation is obtained by pressurising approximately 8-10% of the filtered water at 5-7 bar, almost saturating this flow with dissolved air. When released through a proprietary pressurisation outlet nozzle, pressure is instantaneously reduced and a uniform mass of micro-bubbles are released which ascends through the entire surface of the process unit. Under normal operation the DAFF filtration rate is 7.5 m/h and 8.5 m/h with one filter under backwash.

**BAC.** BAC filtration captures naturally occurring biology in a controlled way to remove organics through bio-assimilation. The BAC design is based on an empty bed contact time (EBCT) of 16 minutes at full flow. This process leads to very long bed life (typically 10–15 years) and the selective removal of those contaminants that can cause taste, odour, chlorine decay, trihalomethane (THM) formation and biofilm regrowth in the distribution network.

Filtration media selection in terms of type, size and bed depth for both DAFF and BAC is critical to ensure optimal process functionality without blinding or over frequent backwashing.

**Treated Water Quality:** Chlorine gas and small amounts of ammonia are added to the main flow, reacting together to form chloramine. Due to long transmission lines, the treated water target for total chlorine is 3.8 mg/l, with a tolerance of ± 0.2 mg/l and the limit for turbidity is 0.15 NTU.

Sample collection

Samples were collected from raw water inflow, post DAFF, post BAC and post chloramination were measured using the online instrumentation which was calibrated and verified using laboratory wet samples.

Water quality analysis

Water samples were filtered through a 0.45 µm glass membrane filter prior to DOC and UV254 measurements. The UV254 absorbance of the water samples was determined using a DR 6000 Spectrophotometer (Hach) with a 1 cm quartz cell. The DOC concentration of the water samples was determined by the UV/persulfate oxidation method, using a Shimadzu TOC Analyser and the biodegradable organic carbon (BDOC) were analysed using the Joret method for BDOC. These samples were also analysed using the Standard Method for Assimilable Organic Carbon (AOC) (AWWA Standard Methods for the Examination of Water and Wastewater 21st Edition 2005, 9217B). Turbidity analysis was undertaken using a Hach 2100Q turbidimeter.

Microbial content

BAC carbon samples were also extracted and examined for their general microbial content (CFU/ml) using the following methodology. A 0.5ml carbon sample was taken from each BAC process cell and was placed in 2ml centrifuge tubes with 1ml desorption buffer and centrifuged for 5 minutes at 14,700 rpm. Samples that were not used immediately were stored at 4°C. Centrifuged samples were spread in triplicate onto R2A agar plates and incubated at 15°C for 10 days. Average plate counts were recorded on day 7.

Analysis of DBPs

Water samples were analysed for

- Trihalomethanes (THMs); chloroform, bromodichloromethane, chlorodibromomethane, and bromoform;
- Haloacetic Acids (HAAs); monochloroacetic, dichloroacetic, trichloroacetic;
- Bromate, Bromide, Chlorate and Chlorite

THMs were measured using USEPA SW 846-8260B. Water samples were directly purged prior to analysis by Capillary GC/MS and quantification was by comparison against an established 5 point calibration curve. This method is compliant with NEPM (2013) Schedule B(3). For HAA Static Headspace GCMS was used. Acids were methylated in situ by incubation with the addition of sodium hydrogen sulfate and methanol followed by static headspace GCMS in SIM mode. Bromate, bromide, chlorate and chloride were measured using USEPA Methods 300A & 300B. This method provides for the simultaneous determination of anions on the Metrosep A Supp 7 – 150 or 250 column using a sodium carbonate eluent, chemical suppression and conductivity detection. An aqueous sample is injected into a stream of eluent of sodium carbonate and passed through an ion chromatography column. According to their affinity to the anion exchange resin (low capacity-strongly basic) anions are separated. After passing through the column solution passes through the Metrohm Suppressor Module (MMS II) to convert the eluent by sodium with H+. After neutralization the eluent flows through a suppressed conductivity detector.
and the amount of anion in the sample is registered as electrical conductivity (height (µS) or area (µS*min)). The absolute concentration of each anion in the sample is determined using external standards.

**Bacteriological Analysis**

Water samples were analysed in the treated water for Thermophilic amoebae and Naegleria spp. For the procedure a 250ml sample is used, adding 2 ml E coli, and centrifuging at 3200 RCF for 15 mins. Aspirate supernatant, before adding 1 ml E coli, resuspend pellet and transfer via pipette to 2 NNA (Non nutrient agar) plates. Dry and incubate at 42 degrees for 3 days. Plates are then screened at a lower magnification and then any presumptive positive amoebas are examined and identified at a higher magnification based on the amoeba cysts present. Heterotrophic Plate Count at 22 C was also monitored using 1 mL volume of sample mixed with molten Yeast extract agar (YEA) in a sterile Petri dish. The plates are then incubated aerobically at 22 ± 2°C for up to 72 hours and 36 ± 2°C for up to 48hours. All colonies that develop are counted and the result is expressed as cfu/mL.

**DISCUSSION AND RESULTS**

**Turbidity removal**

The optimization of the enhanced coagulation and the DAFF system allows achieving a turbidity target of <1.5 NTU for the flotation and <0.15 NTU in the filtration of the DAFF that remains without changes in the BAC outlet.

**Table 1: Turbidity removal, expressed in NTU**

<table>
<thead>
<tr>
<th>Water Quality Parameter</th>
<th>Flotation System (DAFF)</th>
<th>Filtration System (DAFF)</th>
<th>BAC Filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>&lt;0.8</td>
<td>0.08</td>
<td>0.08</td>
</tr>
</tbody>
</table>

**Organics removal**

Dissolved organic carbon concentration could rise up to 7.5 mg/l in the raw water. After the optimization of the enhanced coagulation (varying the pH and coagulant doses) and the DAFF system, the performance of the organic removal has been uniform in these steps considering that the maximum removal was achieved.

Nevertheless since the start of the operations, the BAC has displayed three stages of maturity, as it is shown on figure 1.

The few first months the BAC filters were in “adsorption stage” where most of the organics were removed by adsorption achieving maximum removal of 91%. Then a decrease in organics removal to 64% was observed (the intermediate stage) due to saturation of the carbon surface with retained slow biodegradable components. At this stage attached bacteria started to colonized the surface of the carbon being the organics removed by adsorption and biological activity lower than when in adsorption stage. Then once the carbon was completely saturated the removal of organic carbon became constant, meaning the biological stage of the carbon was achieved.

**Figure 1: Representation of three stages of DOC removal by adsorption and biological degradation**

Table 2 shows the three stages of performance of the BAC and the reductions of organics through the BAC.

**Table 2: Organic removal through the process**

<table>
<thead>
<tr>
<th>Water Quality Parameter</th>
<th>Units (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STAGE 1 Adsorption</strong></td>
<td></td>
</tr>
<tr>
<td>Average DOC removal</td>
<td>%</td>
</tr>
<tr>
<td>Average UV abs 254 removal</td>
<td>%</td>
</tr>
<tr>
<td><strong>STAGE 2 Intermediate</strong></td>
<td></td>
</tr>
<tr>
<td>Average DOC removal</td>
<td>%</td>
</tr>
<tr>
<td>Average UV abs 254 removal</td>
<td>%</td>
</tr>
<tr>
<td><strong>STAGE 3 Biological</strong></td>
<td></td>
</tr>
<tr>
<td>Average DOC removal</td>
<td>%</td>
</tr>
<tr>
<td>Average UV abs 254 removal</td>
<td>%</td>
</tr>
</tbody>
</table>
NOM found in the water samples of this study are represented by hydrophobic components with medium molecular weight of organic matter compounds indicated by low SUVA 254 values using a surrogate measurement of DOC aromaticity (Jie-Chung Lou et al. 2009). Specific UV absorbance (SUVA), is defined as the UV absorbance of a sample, measured at a given wavelength (λ), divided by the DOC concentration, providing the average molar absorptivity of all molecules that comprise the DOC in the sample under test. SUVA, therefore, is a parameter that indicates the nature or quality of DOC.

In the last stage or performance of the BAC the reduction of dissolved oxygen (DO) in the outlet of the BAC also shows evidence of the attached bacteria. The reduction increased comparing with the values during the adsorption phase. Similar results have been reported in previous studies (Seredynska-Sobecka et al. 2006), where desirable ratios of bacteria and protozoa were produced to optimize biofilm growth on the BAC by altering the pH, DO and nutrient levels of the BAC filter feed. The DAFF system increases the DO in the raw water which is beneficial for the attached bacteria.

In the biological stage the AOC and BDOC removal was also monitored along the process units, finding that after the BAC the BDOC remaining was less than 0.05 mg/l but in the outlet of the DAFF, values were higher than 0.25 mg/l. This indicates that the combined process units reduces organic content, producing “biologically stable” water which will avoid the regrowth of the biofilm downstream as reported by several authors (Prévost M et al. 2005).

By reducing the biofilm formation in the network the decay rate of the monochloramine is also reduced.

At the same time the BDOC values obtained in the outlet of the process confirm that ozone will not be necessary in this treatment. AOC values were under measure range. Reducing biofilm formation the decay rate of the monochloramine is also reduced.

Over the same period microbiological analysis was also undertaken to monitor the bacteria contents in three different depths of the BAC filters. The maximum content of colony count was in the bottom of the filter, which was not high (> 600 CFU/mL) probably due to the low values of BDOC. The media samples were taken after the backwash of the filter.

**Bacteriological analysis and DBPs**

No Thermophilic amoebae, Naegleria spp, Heterotrophic Plate Count at 22 C were found in any of the weekly samples after the chloramination system.

Concentration of DBPs, such THM, Bromides, were not found in the treated water after chloramination unless there was presence detected in the raw water. These values were always well below of the Australian Drinking Water Guidelines (ADWG).

**CONCLUSIONS**

This study showed that the selected process DAFF and BAC are very important in removing the organic matter of the water, achieving the turbidity target of 0.15 NTU after filtration, and also the biostability of the water. BDOC values in the outlet of the plant show that the treatment produces biologically stable water without the need of ozone prior to the biological treatment; reducing biofilm formation in the distribution system downstream of the plant which represents a important challenge as the water is sent up to 600 kilometer far away of the plant. There is no evidence of disinfection by products out of the limits of the Australian Drinking Water Standards.
REFERENCES


Biplob Kumar Pramanik, Felicity A. Roddickn, Linhua Fan. 2014. A comparative study of biological activated carbon, granular activated carbon and coagulation feed pre-treatment for improving microfiltration performance in wastewater reclamation School of Civil, Environmental and Chemical Engineering, RMIT University, GPO Box 2476, Melbourne 3001, Australia. Published by Elsevier 2014


