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Removal of natural organic matter at the Gunbower water treatment plant in northern Victoria, Australia

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ABSTRACT

Advanced treatment processes are vital if organic matter is to be removed from water as efficiently as possible. To produce high quality water that has low concentrations of natural organic matter (NOM), the Gunbower water treatment plant (WTP) in northern Victoria, Australia has implemented a number of processes including magnetic ion exchange (MIEX), coagulation, clarifier, ultrafiltration (UF), and granular activated carbon (GAC) filtration. This research evaluated the efficiencies of these processes in removing NOM employing various analytical methods, namely liquid chromatography–organic carbon detector (LC–OCD) and three-dimensional fluorescence excitation emission matrix (3D-FEEM). In addition, the fouling potential of source water and treated water was assessed using a modified fouling index with ultrafiltration (MFI-UF). Biological stability was also tested using a modified assimilable organic carbon (AOC) detection method. The combination of MIEX, clarifier, coagulation, UF membrane, and GAC filtration resulted in dissolved organic carbon (DOC) being removed (from 6.01 to 0.47 mg/L). Furthermore 3D-FEEM analysis revealed that these treatment processes reduced humic and fulvic-like organics. AOC and MFI-UF decreased from 79.94 μg-C glucose equivalents/L and 46,350 s/L^2 in the source water to 4.06 μg-C glucose equivalents/L and 2,057 s/L^2 in the treated water, respectively.

Keywords: Coagulation; Granular activated carbon; Magnetic ion exchange; Natural organic matter removal; Ultrafiltration

1. Introduction

The new Australian Drinking Water Guidelines outline the significance of providing safe drinking water by appropriately managing the water treatment process and water supply system. An understanding of risk associated with treatment systems allows water utilities to apply suitable technologies and solutions to not only reduce risk to public health but also improve the quality of water [1]. Natural organic matter (NOM) in water leads to larger coagulant doses, more membrane fouling, and higher demand for disinfectant. It also reduces the effectiveness of adsorption

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processes and forms harmful byproducts [2,3]. Several treatment options for NOM removal have been evaluated in terms of reducing the impact on the treatment process, producing water using a low disinfectant dose and minimizing biofilm growth in the distribution systems. The optimal selection of treatment processes is influenced by the characteristics of the NOM in the source water and the required quality of treated water. Organic compounds ineffectively removed by conventional treatment processes can be removed by advanced treatment options [4].

The global use of microfiltration (MF) and ultrafiltration (UF) systems for drinking water treatment has drastically increased since the mid-1990s. One reason for this increase is their ability to meet regulatory requirements in terms of water turbidity and reliably removing pathogens such as Giardia cysts and Cryptosporidium oocysts. Another reason is that continual advances in membrane technologies have led to comparable or lower costs (in certain cases) for membrane filtration compared to conventional filtration systems.

In the water treatment plants, GAC is used as a medium for particulates removal and adsorption of organics. The main application of GAC filter is the removal of organic materials by adsorption. The use of GAC in drinking water treatment includes: (i) Taste and Odor (T&O) control; (ii) Synthetic Organic Chemical (SOC) removal for specific chemicals or for an extra treatment barrier; and (iii) Disinfection byproduct (DBP) precursor removal. T&O control has long been the primary reason for using GAC in the drinking water industry. The typical GAC life expectancy in this application is approximately 3–5 years. It has been demonstrated that pesticides and insecticides are present in many river supplies, as one would expect run-off from agricultural areas. GAC can provide an effective barrier to protect the community from pesticides and many other SOCs. In some cases, GAC filter acts also as biofiltration. Biofiltration is a treatment technique in which a granular media filter becomes biologically active overtime for the purpose of removing biodegradable organic constituents.

This study investigated the effectiveness of different processes used in Gunbower WTP in NOM removal. Raw water sourced from Taylor Creek and treated water samples from different treatment process streams used at Gunbower WTP were analyzed in this study. After each treatment process, NOM of water was characterized via liquid chromatography–organic carbon detector (LC–OCD) and three-dimensional fluorescence excitation emission matrix (3D-FEEM). The growth potential of micro-organisms in water after treatment was determined through assimilable organic carbon (AOC). AOC method used is a modified method for rapid and easy detection. AOC assays typically measure the growth of an inoculum in a water sample from which the natural bacterial community has first been removed and inactivated through sterilization. The inoculum grows until stationary phase ($\mu = 0$), following the principle that the growing bacteria assimilates all the AOC in the water. The net growth of the bacteria is measured and then converted into an AOC (or AOC-equivalent) concentration [5]. However, traditional AOC methods (i.e. cell growth-based method) can take up to 3–7 d to complete after which it is often too late to take action to control the AOC levels. In this study, cell growth was measured in terms of fluorescence intensity instead of counting of cell to reduce the detection time. In addition, fouling potential in the membrane of raw water and treated water was evaluated using modified fouling index with ultrafiltration (MFI-UF).

2. Materials and methods

2.1. Gunbower water treatment plant

The Gunbower water treatment plant (WTP) which provides treated water for the township of Gunbower in northern Victoria, Australia has a 0.65 ML/d capacity (based on 22 h operation per day). The treatment train for the Gunbower WTP is presented in Fig. 1. It comprises an in-line strainer, a magnetic ion exchange (MIEX) tank, a clarifier, an ultrafiltration (UF) membrane reactor, a granular activated carbon (GAC, wood-based) filter (installed in 2012), a disinfection module, and individual ancillary systems. In this plant, MIEX and flocculant are added prior to UF to remove hydrophobic and hydrophilic organics. GAC filter is used as post treatment to UF to remove taste and odors causing compounds and trihalomethane (THM). These treatment processes focuses on producing biologically stable water for distribution by removing NOM from in the source water.

The water flows through the MIEX contactor tank into the clarifier and from the clarifier to the membrane feed tank. Water is drawn from the membrane feed tank by the membrane feed pumps to the membrane system skid. Following filtration through the membranes, water flows under gravity through the GAC tank, then into the clean water storage tanks. Here, it is dosed with chlorine and caustic soda for pH correction prior to entering the distribution network. The MIEX system is a proprietary system supplied by Orica Australia. Approximately 1,200 L of MIEX resin was used in the contactor. For every 1 ML

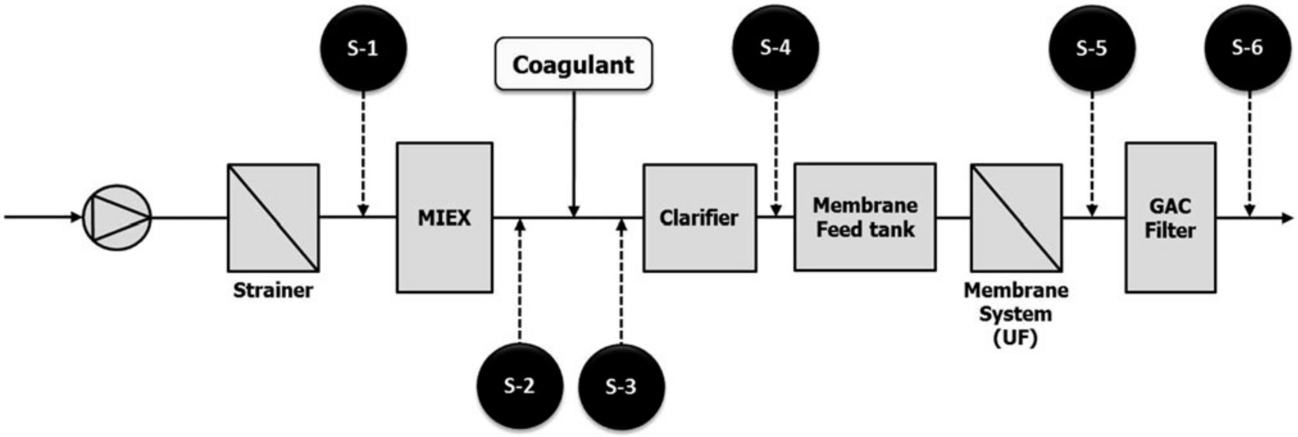

Fig. 1. The schematic diagram of the treatment stream in the Gunbower WTP and location of sampling points.

of water treated 1,000 L of MIEX Resin is regenerated producing 300 L of high organic waste. A general description of the operation of the system can be found at www.miexresin.com. Aluminum chlorohydrate (ACH, Megapac 23, Omega Chemicals) with an aluminum active content of 23–24% as Al_2O_3 was used to coagulate the raw water (on average, a dose of 5.5 mg/L of ACH was employed). For pH adjustment, 5.9 mg/L of caustic soda solution (31.5%) was used in both the raw water (upstream of the clarifier) and the final treated water. The UF membrane filtration used at the Gunbower WTP was a Pall AP3 system (a PVDF membrane with a pore size of 0.1 μm). It has its own neutralization system for treating clean in place (CIP) waste prior to wastewater being discharged to the sewer. The empty bed contact time (EBCT) of the GAC filter is 15 min.

In the Gunbower WTP, chlorine was added into the GAC filter. Thus, the GAC filter functioned in the adsorption mode rather than the biological mode. The dissolved organics which were not removed in the previous processes are removed in the GAC filter by adsorption. The GAC filter operates for a maximum of 22 h per day. The GAC medium is backwashed once a week or when the head loss exceeds a preset level. Air–water backwashing is employed for a short time depending on how much head loss developed. The GAC backwash collects in a wash water tank from where it drained to sewer line (prior to clarifier, S-3). It should be noted that washwater was not sent back to UF. Gaseous chlorine was used to disinfect the treated water. Application of advanced NOM removal processes such as MIEX, pre-flocculation, and UF results in a significant decrease in chlorine demand and THM formation potential (THMFP) [6].

2.2. Sample locations

Fig. 1 shows the entire treatment stream and sampling locations in the Gunbower WTP. Raw water collected from Taylor Creek which runs adjacent to the Gunbower WTP was sent through a strainer prior to passing through the MIEX process. Sample location number 1 (S-1) is where the raw water enters the MIEX process. Treated water after MIEX treatment (sample location number 2, S-2) was coagulated using ACH coagulant. Coagulated water (sample location number 3, S-3) was sent to the clarifier to remove the turbidity. Then, the clarified water (sample location number 4, S-4) was passed through the UF membrane system. Finally, UF filtered water (sample location number 5, S-5) was treated by the GAC adsorption (sample location number 6, S-6) prior to disinfection. Samples were collected in 40-L container at two different times (between 21 and 23 August, 2012) from each sampling location. The flow rate was 30 m^3/h. Hydraulic retention time (HRT) for each of the major process was approximately 6 h. Thus the sampling was made every 6 h.

2.3. Analyses

The values of pH, turbidity (NTU), conductivity (mS/cm), and salinity (g/L) were measured by a pH meter (HANNA, HI902), a turbidity meter (HACH, 2100P), and a conductivity and salinity meter (WTW, LF330), respectively, at room temperature (25 ± 1.0˚C). UV absorbance at 254 nm (UV_{254}) was measured with a Shimadzu UV/VIS-1700 spectrophotometer. UV_{254} is a useful surrogate for DOC although it tends to include only the more complex NOM. The ratio of

UV_{254} to DOC (specific UV absorbance—SUVA) is also often used to characterize organics.

2.3.1. NOM characterization

Samples were filtered through a 0.45 µm syringe membrane filter before characterizing the NOM in terms of dissolved organic carbon (DOC).

2.3.1.1. Dissolved organic carbon. DOC is the most commonly used parameter to quantify NOM. DOC was measured by DOC-LABOR liquid chromatography–organic carbon detector (LC–OCD). The LC–OCD system utilized a Toyopearl TSK HW50S column (TOSOH Bioscience GmbH, Stuttgart, Germany), with phosphate buffer mobile phase of pH 6.4 (2.6 g/L KH_2PO_4 and 1.5 mol/L Na_2HPO_4) at a flow rate of 1.1 mL/min. The LC–OCD analysis separates the total DOC into hydrophilic and hydrophobic fractions. Furthermore, the size exclusion chromatography (SEC) column in the LC–OCD system separates the hydrophilic organic fractions according to their molecular size at different retention time. The separated compounds are detected by an ultraviolet (UV) detector (absorption at 254 nm) and an OCD detector (after inorganic carbon purging).

2.3.1.2. Detailed organic fractions. Depending on the size of the molecules, the different fractions of the organic matter can be identified and quantified. DOC was divided into two parts by LC–OCD. Hydrophobic organic carbon (HOC) was calculated as the difference between DOC and chromatographic DOC (CDOC or hydrophilic DOC). All organic matter retained in the column was defined as hydrophobic, and it could constitute either dissolved hydrocarbons or microparticulates including humics. CDOC was calculated from the area enclosed by the total chromatogram [7].

In LC–OCD, hydrophilic DOC in water mainly contains biopolymers, humic substances (or humics), building blocks, and low molecular weight neutrals [7]. Biopolymers have very high molecular weight (20,000–100,000 g/mol) and represent compounds such as polysaccharides amino sugars, polypeptides, proteins, hydrophilic fraction, and non-UV absorbing. In surface water, biopolymers mostly exist as colloidal transparent exopolymeric particles (TEP) and polysaccharide. Humics represent compounds with molecular weights of approximately 1,000 g/mol. Building blocks are defined as humic hydrolysates, which are subunits of humics with molecular weights between 300 and 450 g/mol. They are mainly weathered and oxidation products of humics. Low molecular weight neutrals are only low-molecular weight weakly charged hydrophilic or slightly hydrophobic compounds, for example, alcohols, aldehydes, ketones, and amino acids.

2.3.1.3. Three-dimensional fluorescence excitation emission matrix (3D-EEM). The 3D-EEM technique is rapid, selective, and sensitive and offers information on the fluorescence characteristics of compounds by changing the excitation and emission wavelength simultaneously. The fluorescence in different spectral regions is associated with different types of functional groups. Fluorescence signals are basically attributed to protein-like fluorophores, humic-like fluorophores and characterized dissolved organic matter in water using fluorescence spectroscopy [8].

Before optical analysis, the samples were first allowed to warm to room temperature after filtering the water through a 0.45 µm membrane filter. Fluorescence measurements of dissolved organic matter in water samples were carried out using a Varian Eclipse Fluorescence Spectrophotometer. EEMs were recorded by scanning emission wavelengths from 250 to 500 nm repeatedly at excitation wavelengths scanned from 220 to 400 nm by 5 nm increments. The excitation and emission bandwidths were both set at 5 nm. The fluorometer was set at a speed of 3,000 nm/min, a PMT voltage of 700 V, and a response time of 2 s.

It can be seen that four characteristic peaks were observed in EEMs including Peak A which indicates humic-like substances (ex/em = 250–260/380–480 nm); Peak C which indicates fulvic-like substances (ex/em = 300–370/400–500 nm); Peak B which indicates tyrosine-like and protein-like substances (ex/em = 270–280/300–310 nm); and Peak T which indicates tryptophan-like and protein-like substances (ex/em = 270–280/320–350 nm). In this study, the sum of peaks B and T was considered as a protein-like peak substances (ex/em = 270–280/300–350 nm). This analysis is only semi-quantitative since the average value of fluorescence intensities in the range of ex/em of each peak is used when comparing the relative abundance of organics.

2.3.2. Fouling potential

Fouling potential was measured using modified fouling index with ultrafiltration (MFI-UF). In each MFI-UF test, new membranes (with pore size of 17.5 kDa and diameter of 47 mm) were used to avoid the residual fouling. The raw water and treated water were pressurized at 2.0 bar (207 ± 3 kPa) using N_2 gas at room temperature. The detailed procedure involving MFI-UF has been documented elsewhere [9].

2.3.3. Biological stability

AOC indicates the biological stability (or biostability) of product water. The quantitative evaluations with AOC can be made to determine the relative biostability of the product water compared to that of the original source water and water being distributed to consumers [10]. Therefore, reducing AOC in water is an important part of the water treatment process since even low concentrations are enough to support bacterial growth in the distribution system [11].

The method was modified based on theoretical aspects of the individual methods that apply in surface water samples using PAO1-GFP strain to measure the cell growth using fluorescence. The maximum growth of PAO1-GFP in water samples was measured as fluorescence intensity and corresponded to the AOC. The PAO1-GFP (green fluorescent protein) utilized was *Pseudomonas aeruginosa* strain which is resistant to chloramphenicol (50 μg/mL). PAO1-GFP was stored as a stock at −80˚C. For each set of experiments, bacteria were streaked onto a Luria-Bertani (LB) agar medium plate and cultured for 18–22 h at 37˚C. An individual colony was cultured in LB medium and then amplified in a larger volume to prepare aerated, log phase bacteria by rotary shaking at 37˚C until 1×10^9–2×10^9 CFU/ml was achieved as determined by the spectrophotometer (optical density at 600 nm = 0.6). The CFU of the bacteria was quantified by plating serial dilutions on LB agar medium.

3. Results and discussion

3.1. Water quality

Table 1 summarizes the basic characteristics of raw water (S-1) and treated water (S-2 to S-6). The pH was maintained at neutral pH ranges between 6.52 and 7.40 during the treatment. The turbidity of raw water was quite high at 26.6 NTU. Turbidity increased slightly during the coagulation process because the presence of coagulant in water. Coagulation by itself does not reduce turbidity. In fact, turbidity may increase during the coagulation process due to additional insoluble compounds that are generated when chemicals are added. However, this decreased to 7.0 NTU following the clarifier process. This value further declined to a clean water level of 0.4 NTU after UF membrane filtration and GAC adsorption. The processes of flocculation, sedimentation, and filtration should be used together with coagulation to reduce suspended solids and turbidity. The turbidity removal was more than 98% compared to source water when all processes were combined.

Organic substances absorb ultraviolet (UV) radiation, and thus an ultraviolet absorbance (UVA) measurement at 254 nm is related to the concentrations of organic compounds. SUVA is the ratio of UV_{254} and the DOC concentration and it serves to estimate the fraction of aromatic content of DOC [12]. It can be seen from Table 1 that the SUVA value of raw water was 2.54 L/mg m but this value decreased to 1.96 L/mg m after the coagulation process which indicates a reduction of aromaticity in NOM. The SUVA value increased with hydrophobic DOC contents (UV_{254} absorbing organic compounds). This trend can be supported using the detailed organic fraction results discussed in Section 3.2. Humic substances concentration increased in the S-4 sample (after clarifier) which led to an increase in the SUVA value of the S-4 sample. Here, humic substances were detected using a UV detector in the LC–OCD as shown in Table 1. UV_{254} correlated well ($R^2 = 0.99$) with the DOC measurement of raw water and treated water samples.

DOC concentration of raw water was 6.01 mg/L. MIEX and coagulation processes reduced the DOC by 74%. The DOC decreased further to 0.47 mg/L when the UF membrane and GAC adsorption processes were employed. This is equivalent to around 92% removal, indicating that the entire DOC removal process in the Gunbower WTP could produce a superior quality of water. The removal of DOC fractions using each process is discussed in detail in the following section.

Table 1
Summary of water quality for samples obtained from the Gunbower WTP

Samples	Description	pH[a]	Turbidity[a] (NTU)	UV_{254}[a] (cm^{-1})	DOC[a] (mg/L)	SUVA[a] (L/mg m)
S-1	Raw water	6.52	26.6	0.153	6.01	2.54
S-2	After MIEX	6.70	24.1	0.041	1.98	2.07
S-3	After coagulation	6.86	33.2	0.031	1.58	1.96
S-4	After clarifier	6.70	7.0	0.040	1.52	2.63
S-5	After UF	7.27	0.5	0.021	0.93	2.26
S-6	After GAC	7.40	0.4	0.014	0.47	2.98

[a] Average value.

Table 2
Detailed organic fractions of water samples

Samples	DOC^{a} (mg/L)	Hydrophobic DOC^{a} (mg/L)	Hydrophilic DOC^{a} (mg/L)	Biopolymers^{a} (mg/L)	Humic substances^{a} (mg/L)	Building blocks^{a} (mg/L)	LMW organics^{a} (mg/L)
S-1	6.01	0.710	5.298	0.343	3.195	0.819	0.941
S-2	1.98	0.554	1.425	0.252	0.402	0.208	0.563
S-3	1.58	0.399	1.182	0.060	0.272	0.073	0.778
S-4	2.18	0.372	1.154	0.032	0.612	0.095	0.973
S-5	0.93	0.195	0.734	0.021	0.258	0.014	0.444
S-6	0.47	0.085	0.386	0.012	0.118	0.022	0.233

^{a}Average value.

3.2. Detailed organic fractions

As indicated in Table 2 and Fig. 2, river water (S-1) consisted of 12% of hydrophobic DOC and 88% of hydrophilic DOC. Humic substances constituted approximately 60% of the hydrophilic DOC fractions. The MIEX process reduced the DOC from 6.01 to 1.98 mg/L (67% of removal efficiency). MIEX removed only 27% of biopolymers from raw water while humics removal was more than 87% (from 3.195 to 0.402 mg/L). The MIEX® resin has strong base functionality and therefore is able to exchange weak organic acid ions like humic acid and fulvic acid at the neutral pH. High selectivity of strong base resins for highly charged organic ions enables these ions to be effectively removed at very low influent concentrations (typically <15 mg DOC/L) [13,14].

Coagulation by ACH led to the significant reduction of biopolymers (more than 83% compared to S-1). This in turn led to a further 28% reduction in the hydrophobic DOC fraction after MIEX treatment. ACH solution is a complex and dynamic mixture of positively charged polynuclear aluminum species with a molecular weight of more than 1,000 Da. When applied to water, these species interact with and destabilize negatively charged colloidal matter such as inorganic particles and the high molecular weight organic compounds, for example, biopolymers and humic substances that largely constitute NOM. The polynuclear species also hydrolyze to form dense flocs of aluminum hydroxides that further act to entrap particles and remove some organics [15]. Negatively charged organics such as humics were removed preferentially by coagulation. LMW organics mainly consist of non-polar or neutral organics. As presented in Table 2, large quantities of biopolymers and humics were removed by coagulation. Coagulation was conducted with pH adjustment and consequently, the concentration of LMW-neutrals slightly increased after coagulation with pH adjustment since it led to charge neutralization of colloidal materials. However, coagulation did help to reduce organics in the subsequent clarifier and UF filtration processes.

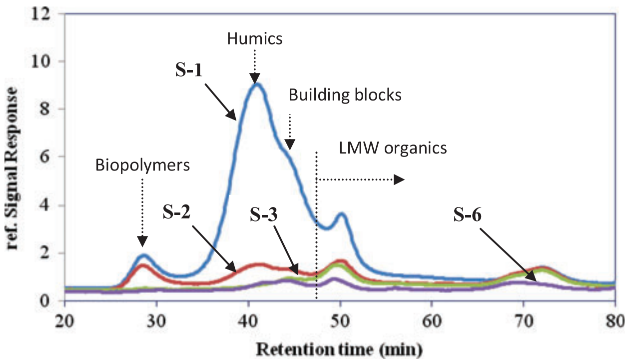

Fig. 2. LC–OCD chromatograms of samples.

During the clarification process, DOC concentration only decreased slightly. The UF membrane filtration process reduced the DOC further to 0.93 mg/L. UF is considered to be a very effective technology for removing turbidity, bacteria, and virus, while NOM rejection (having high molecular weight and highly charged hydrophobic organic compounds such as humic substances) by UF is often limited [16]. GAC filtration, which is the final DOC removal process, reduced humic substances and LMW organics concentrations (that remained after UF filtration) to 0.118 and 0.233 mg/L, respectively. This is the reason why GAC was used as final polishing treatment. This indicated that the removal processes, especially MIEX, UF membrane coupled with coagulation and GAC filtration, were quite efficient in removing the DOC. The GAC filter removed the remaining of humics and LMW organics. The final product water revealed only 0.47 mg/L of DOC, the majority of which was LMW organics (0.233 mg/L) and humics (0.118 mg/L). Babi et al. [17] found that the organic removal by GAC was

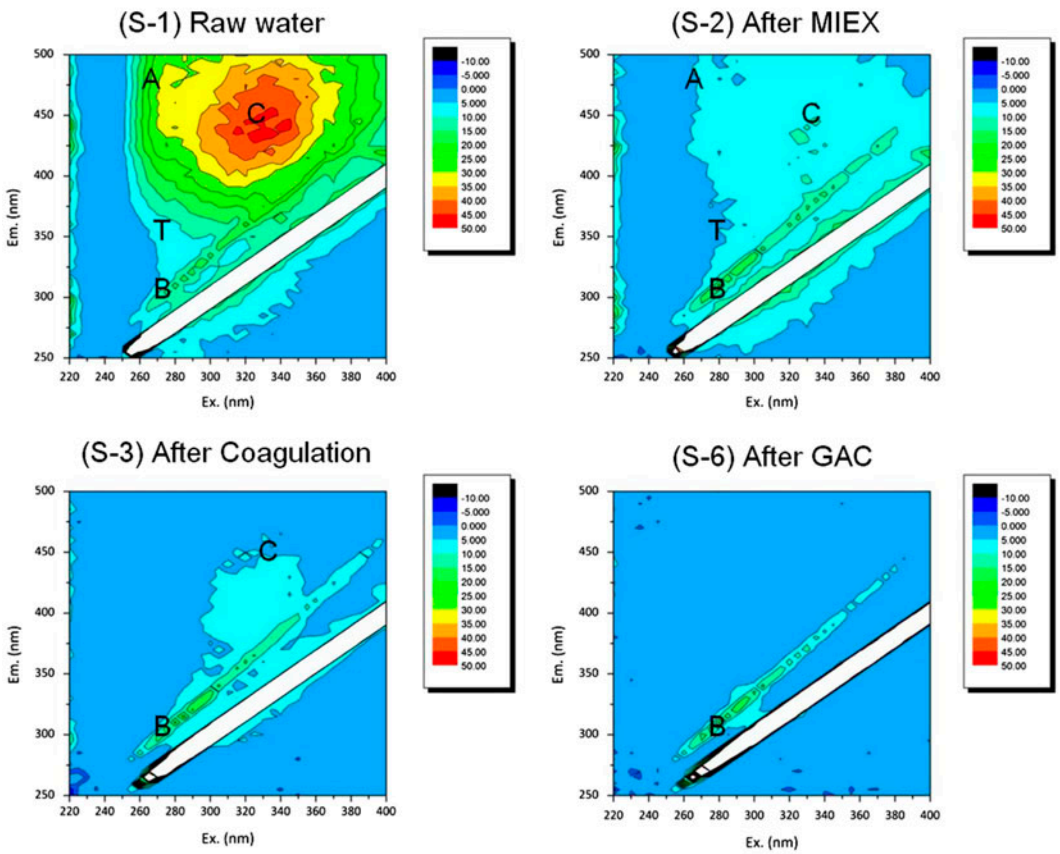

Fig. 3. 3D-FEEM spectrums of samples in the Gunbower WTP.

more efficient. The removal of trihalomethane (THM) and most of the DOC should be attributed to adsorption by GAC in the adsorber bed. Thus, GAC treatment helped in further removal of DOC in the water treatment plant.

3.3. Fluorescence (3D-FEEM)

A typical 3D-EEM contour plot of raw water (S-1) and treated water (S-2 to S-6) is shown in Fig. 3. The relative organic abundances based on peaks in Fig. 3 are given in Fig. 4. Gone et al. [18] discovered a strong linear relationship between DOC removal and fluorescence intensities in surface water. The combination with the potential for access to the removal efficiency of the different fluorophores means that fluorescence spectroscopy offers a robust analytical technique in conjunction with the conventional approach using only DOC to evaluate organic removal efficiency in the water treatment plants. As can be seen from Figs. 3 and 4, protein-like organics (peaks B and T) were slightly altered. MIEX treatment reduced protein-like organics from 8.15 to 7.15 a.u. Subsequently, coagulation and GAC filtration further reduced this to 6.34–5.05 a.u., respectively. On the other hand, the reduction of humic-like and fulvic-like organic compounds was relatively significant. Conversely, the reduction of organics (obtained from 3D-FEEM analysis) by clarifier (S-4) and UF membrane filtration (S-5) was not significant. After GAC filtration (S-6), almost all humic-like and fulvic-like

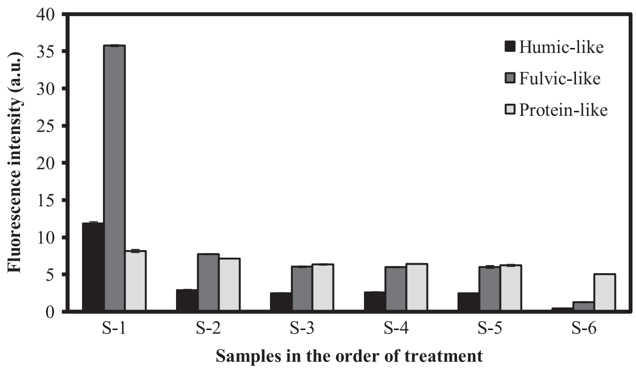

Fig. 4. Fluorescence intensity of samples in the Gunbower WTP.

peaks disappeared and their average intensities were 0.46 and 1.26 a.u., respectively. These values were negligible compared to raw water (S-1: humic-like = 11.85 a.u. and fulvic-like = 35.76 a.u.). It indicated that organic removal processes (MIEX, coagulation and GAC adsorption) were effective in producing water with low humic and fulvic-like organics.

3.4. Fouling potential

To predict the membrane fouling of raw water and treated water, MFI-UF was measured and the values are shown in Fig. 5. MFI-UF is useful for analyzing the role of colloidal and dissolved matter in water. MFI was determined from the slope ($t/v^2 = s/L^2$) of the straight line obtained from a graph of t/v vs. v. Here, t and v are filtration time (s) and total permeate volume (L), respectively. This value is used as a cake fouling index and it has a close relationship with organic fouling. The MFI-UF of raw water (S-1) was 46,350 s/L^2. MIEX treatment reduced this value by half (24,886 s/L^2). Further, ACH coagulation reduced the MFI-UF value to 2,709 s/L^2. Finally, the GAC filtration process produced water with low cake fouling potential of 2,057 s/L^2. MFI-UF is associated with both particulate fouling potential and organic fouling potential of feed water [19,20]. However, it is not clear how much it is related to DOC concentration and turbidity since fouling phenomena are complex in the target membrane system. The results confirmed that MIEX and coagulation reduced the DOC from the source water and this indicates that the MFI-UF value is related more closely to the organic fouling potential.

3.5. Biostability

Only a small fraction of total organic carbon in surface water is utilizable by bacteria. However, this fraction will lead to proliferation of bacteria in the treatment and distribution systems. Undesired growth of bacteria has known problems such as biofilm formation and biofouling. As a consequence, treatment plants are often designed with specific steps to remove the biodegradable fractions and to increase biological stability [5]. Hence, in order to monitor, control, and optimize the removal systems, it is important to quantify the biodegradable organic fractions accurately and rapidly.

In the study, the modified AOC method using PAO1 with fluorescence was used and the results are presented in Fig. 6. The modified method used a different strain (PAO1-GFP) to monitor the biological growth with fluorescence measurement. This method led to a faster and easier AOC detection compared to van der Kooij's AOC method [5]. AOC concentration of raw water (S-1) was 79.94 (±7.62) μg-C glucose equivalents/L. This value was reduced to 27.59 (±0.89) μg-C glucose equivalents/L (S-2) and 21.71 (±1.24) μg-C glucose equivalents/L (S-3) by the MIEX and coagulation treatment processes, respectively. AOC was not removed both by the clarifier (S-4) and UF filtration (S-5). GAC filtration, however, reduced the AOC value significantly to 4.06 (±0.38) μg-C glucose equivalents/L, indicating that the product water maintained good biostability. The van der Kooij's AOC method states that heterotrophic bacteria growth is limited when the AOC value was less than 20 μg-C/L. When AOC levels exceed 50 μg-C/L, a significant growth of coliform bacteria was observed [5]. In our study, the AOC value obtained with the modified AOC method was less than 5 μg-C/L. AOC value in product water after the GAC filtration step (S-6) was biologically safer compared to raw water (S-1). Reduction in biological regrowth (AOC value) was clearly observed with the treatment processes in the Gunbower WTP.

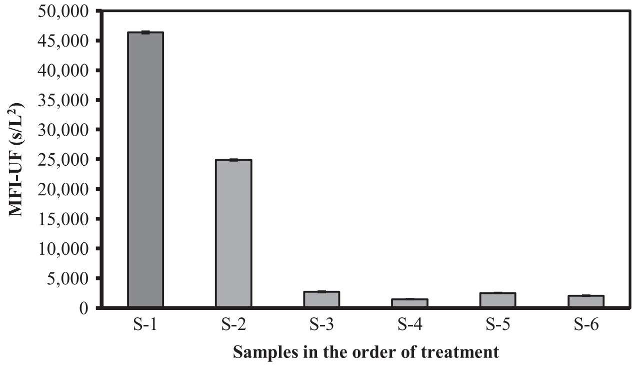

Fig. 5. MFI-UF values of samples in the Gunbower WTP.

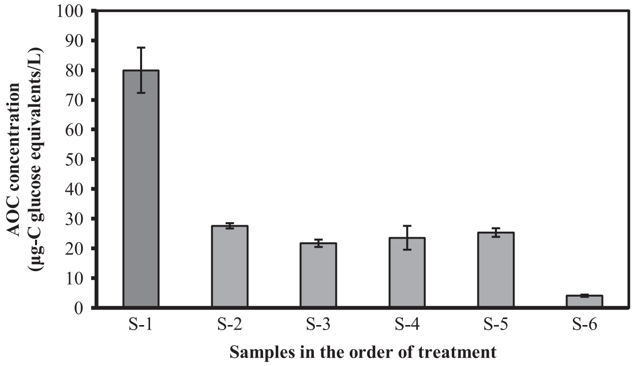

Fig. 6. AOC concentration of raw water and treated water.

4. Conclusion

The Gunbower WTP in Victoria, Australia comprised five NOM removal processes: MIEX, coagulation, clarifier, UF filtration, and GAC filtration. MIEX led to a significant removal of organics from source water (around 67% in term of DOC), especially humics and building blocks. Coagulation was effective in removing biopolymers, humics, and building blocks that remained after the MIEX process. UF membrane filtration coupled with coagulation produced low turbidity water after the clarifier and further reduced DOC levels. GAC filtration adsorbed the remaining humics and low molecular organics. These organic removal processes reduced humic and fulvic-like organics in source water. As a consequence, the biostability of product water improved significantly.

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