Drinking water treatment – understanding the processes and meeting the challenges

Don Bursill

Cooperative Research Centre for Water Quality and Treatment, Salisbury, South Australia

Abstract On and follow Natural organic matter (NOM) derived from soil and vegetation in water catchments is the key factor influencing most, if not all water treatment processes. The structure of the NOM and its involvement in water treatment processes requires better understanding. It seems likely that a better understanding of NOM reactions could lead to far better predictive capacity for water treatment designers and operators. Certainly the removal of NOM as a first step to the production of drinking water has many attractions. This paper provides an overview of work done by the author and many of his colleagues to advance this issue.

Keywords drinking water treatment, natural organic matter, membranes, activated carbon, MIEX®

Introduction

Drinking water treatment really has only three main goals, i.e.

- to provide safe water
- to provide aesthetically pleasing water, and
- to ensure that the technology applied does not create further problems.

Of course there are many issues to be resolved in meeting these objectives. Our understanding of the issues changes over time and this can create a different view of the technology that has been applied and the importance of any problems associated with processes. Clearly the removal or inactivation of pathogens through filtration or disinfection has been and continues to be the key requirement to ensure safe water. The need to remove taste and odour compounds, whether from natural origins or man made became an important additional requirement to conventional treatment processes. As analytical methodology improved substantially and we became aware of the contamination of our environment – particularly the aquatic environment, this led to even more widespread interest in enhanced treatment processes to remove these contaminants from our water supplies. All the while, concerns have been raised about the health implications of trace organic pollutants and this has led to increased suspicion of the safety of public water supply systems. Curiously, our capacity to study the health impacts of water pollutants at the trace levels normally present has not been well developed. The inability of health authorities to be more definite in this regard only creates further impetus for conservatism with regard to the provision of increasingly more sophisticated water treatment technology.

The concern with pathogen contamination is always present, particularly in systems reliant on surface water sources. Viruses were the main concern for many years – the greater resistance of some to commonly used disinfection processes being the main issue. However, *Cryptosporidium* has changed the scene and has clearly placed a new dimension on water treatment. At the moment, one cannot really rely on disinfection and one needs to ensure that physical removal processes are optimal. Water treatment facilities previously considered adequate in certain instances are perhaps no longer satisfactory where challenges from this pathogen are high.

As knowledge develops, the emphasis changes, but it seems that in most cases the

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tendency has been to build add-on technology to conventional processes while largely avoiding careful study of the underlying fundamentals. Most of the processes employed in drinking water treatment are affected by natural organic matter (NOM) in the water. In South Australian water supplies where NOM levels are generally high, the impacts can be quite noticeable. However, the same effects can be readily seen in waters with lower NOM levels; even in relatively clean groundwater sources. This paper examines the effect of NOM on water treatment processes and describes a process that is designed to significantly reduce NOM as a first step in treatment. The subsequent water quality and operational benefits are easily demonstrated.

Water treatment objectives and key issues

In the provision of safe drinking water, the main issues of concern include:

- microbiological quality
- disinfection by-products (DBPs)
- algal toxins
- pesticides and other anthropogenic organic compounds (the micropollutants)
- lead, arsenic and other toxic inorganic substances
- endocrine disrupting chemicals and pharmaceuticals.

The main issues in achieving aesthetically pleasing water are colour, turbidity, taste, odour, salinity and hardness. These issues are less complicated but can usually determine the treatment approach adopted in any given situation and therefore greatly influence the cost of treatment.

Clearly, dealing with the above issues for achieving health and/or aesthetic objectives is not normally dealt with in isolation. There are overlaps and inter-relationships that should not be overlooked. If they are overlooked then this can cause more problems in the third objective area, i.e. that the technology applied does not create further difficulties. The issues here include:

- DBPs
- chemical residuals – Aluminium, iron, chlorine, manganese, polyelectrolytes, etc.
- corrosivity
- bacterial regrowth
- taste and odours.

The range of technology options at our disposal has not increased greatly in the last few decades, although more sophisticated treatment facilities are more frequently being chosen to meet the perceived demand from the community than was the case thirty years ago. The main processes and the issues associated with them are given in Table 1 below.

Table 1 Issues associated with key processes in drinking water treatment

Process	Issues
Flocculation/sedimentation/sand filtration	Process effectiveness, raw water quality impacts on process efficiency, sludge disposal, residuals (Al, Fe, etc.), organic removal not good, Crypto removal efficiency
Disinfection	Effectiveness, DBPs, regrowth, residual management, taste & odour (direct and indirect), corrosivity
Activated Carbon	Cost, effectiveness, regeneration, blinding, waste disposal
Membranes	Cost, fouling, energy use, colour removal

NOM is the key

All of the above processes are affected by NOM. NOM rapidly chelates with aluminium and iron salts used for flocculation to the extent that the concentration and character of the NOM present controls the dosage requirements for flocculation with conventional inorganic flocculants. This is demonstrated in Figure 1 which shows that as increasing amounts of NOM are removed from the water the alum required for optimum turbidity removal is significantly reduced.

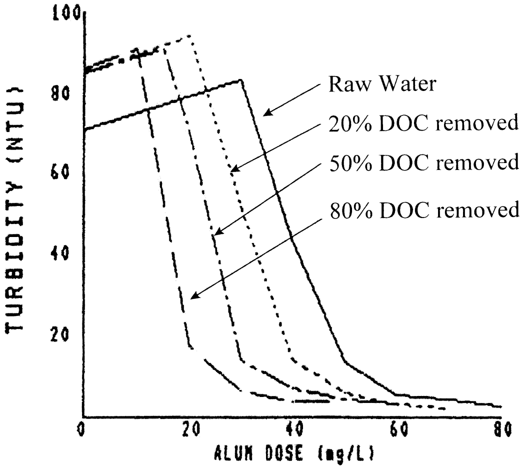

Figure 1 Effect of DOC removal on alum requirement for flocculation of turbidity. Raw water sampled from River Murray (Mannum).

NOM also reacts with chlorine and other disinfectants and thereby controls the level of dosing required to achieve the desired residual. In the case of chlorine, where most operators are seeking to achieve a residual chlorine level through much of the distribution system, NOM is the most significant factor in determining the rate of chlorine decay. Of course the formation of DBPs has been one of the bigger issues of concern relating to disinfection processes. NOM is the precursor material for the generation of DBPs. These points are illustrated in Tables 2 and 3. In addition to the above disinfection impacts, the oxidation agents used as disinfectants produce more biodegradable products on reaction with NOM. These products can be measured in various ways. Table 4 shows the impact of ozonation on the NOM in a natural water sample from Myponga Reservoir in South Australia. The bioavailable products are measured as Bacterial Regrowth Potential and expressed as acetate equivalents. These products provide increased potential for the growth of bacteria and other micro-organisms in the distribution system. It is probable that these effects are responsible for most of the microbiological compliance failures in otherwise well managed water supply systems.

Table 2 Effect of NOM (expressed as dissolved organic carbon – DOC) on initial 30 min chlorine demand for Myponga Reservoir, South Australia

DOC (mg/L)	Chlorine Demand (mg/L)
8.1	4.1
5.1	2.6
3.9	1.7
3.0	1.0

Table 3 Effect of NOM on trihalomethane formation potential

DOC (mg/L)	THM Formation Potential (μg/L)	DOC (mg/L)	THM Formation Potential (μg/L)
11.4	243	7.0	395
9.3	154	6.0	373
8.5	143	4.9	294
6.6	189	3.7	272
5.3	77	3.0	183
4.4	55	2.4	169
		1.8	152
Lexton Reservoir, Victoria		Wanneroo Ground Water, Western Australia	

Table 4 Effect of ozone oxidation on bacterial regrowth potential

Sample	DOC (mg/L)	Acetate Equiv.* (μg/L)
Myponga	5.9	63
+1 mg O_3/L	5.8	125
+2 mg O_3/L	5.7	310
+6 mg O_3/L	5.3	678

*Using bacterial regrowth potential

Membrane filtration technology is one of the real water treatment advances of the past twenty years. Costs are coming down and the reliability and performance is improving. The range of membrane types is also expanding, making it difficult to make general statements about basic performance. However, it seems that micro-filtration is the most likely membrane process to be widely used in drinking water treatment in the future due to its performance on pathogen removal while achieving relatively low energy consumption. However, micro-filtration membranes do not remove colour and suffer from fouling. This has led to much interest in hybrid membrane evaluations involving chemical and/or physical processes to remove colour and reduce the incidence of organic fouling.

Activated carbon in various forms is the preferred method of removal of pesticides and other man made organic chemicals as taste and odour compounds resulting from biological activity in the catchment or water storage. Powdered activated carbon provides the most flexible approach to carbon application, but the carbon is not able to be re-used and is considered a toxic waste in some countries. GAC is the preferred approach where most regular contamination is present and/or disposal of powdered carbon presents difficulties. Regeneration costs are substantial and if NOM levels are high, resulting in rapid blinding of the carbon, this can preclude its use altogether.

Figure 2 shows the significant impact that NOM has on the performance of activated carbon in the removal of methyl isoborneol (MIB) from water. MIB is one of the key causes of off flavours in water systems in Australia and is produced by algal activity.

Figure 3 further illustrates this point and demonstrates that in this instance it is the lower molecular weight fraction of the NOM that is responsible for the blinding effect. This is the fraction that is less readily removed by conventional treatment methods.

Why not remove NOM first?

A better understanding of the influence of NOM on water treatment processes would provide reliable predictive capacity for water treatment design engineers and for operators.

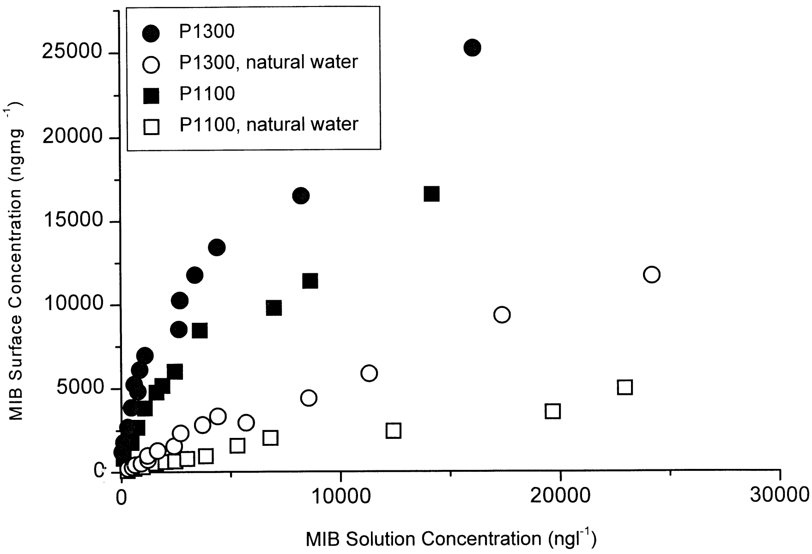

Figure 2 Effect of NOM on removal of MIB by activated carbon.

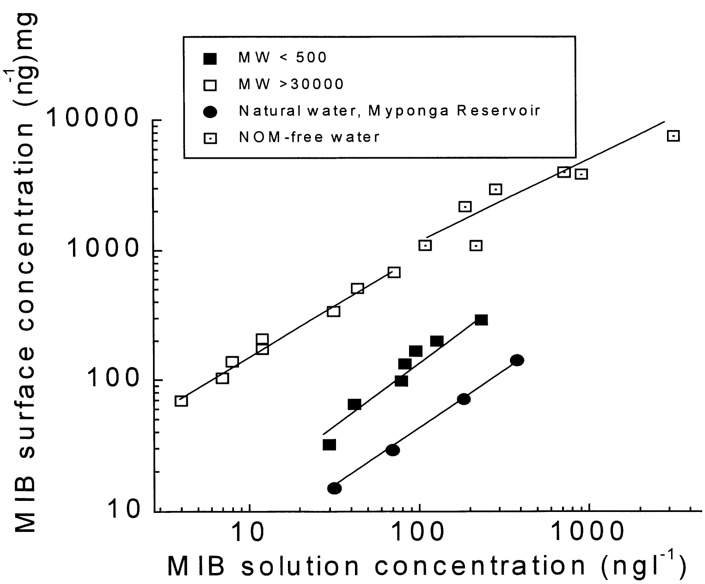

Figure 3 Effect of NOM on removal of NOM by activated carbon.

However there would appear to be clear benefits regarding the stability of process performance and with the eventual water quality outcomes if an effective method of NOM removal could be employed as a first step.

There is something to be gained from enhancing the performance of conventional treatment. Enhanced coagulation has been reported from a number of workers with varying results. This approach has been in use in South Australia since 1993 although the practice was first evaluated in 1982 as part of a broader study on the minimisation of trihalomethane formation.

Figure 4 shows the relationship between alum dose and NOM removal at a range of pH

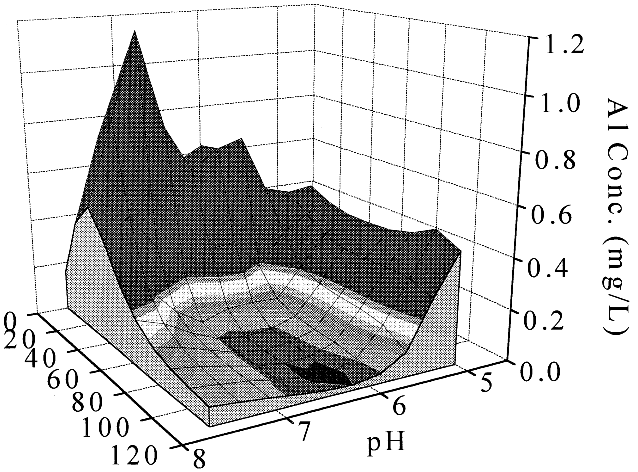

Figure 4 The optimisation of NOM removal as a function of alum and pH.

values. Also shown are the residual aluminium levels resulting from treatment at various pH and alum dosage conditions employed. These results are shown for one particular South Australian water source, but are generally typical of the behaviour of all water sources in the State. It can be seen from this figure that NOM removal can be optimised through the careful management of the pH of coagulation and optimisation of alum. However, it is difficult to achieve more than 60% NOM removal on a regular basis. Also it is clear from our work that the lower molecular weight fraction of NOM is less effectively removed by coagulation and it is this fraction which seems to be more influential in reducing the effectiveness of activated carbon and in the promotion of bacterial regrowth. Nevertheless, enhanced coagulation has resulted in a significant reduction in trihalomethane formation in South Australian water systems that previously often exceeded 200 µg/l. Similarly, greatly improved distribution system management has been a benefit, with no difficulty in always meeting the exacting Australian Drinking Water Guidelines recommendations for microbiological quality. This is a significant achievement given the very poor source water quality that South Australia has to contend with.

The MIEX® process

MIEX® is a process based on the incorporation of magnetic iron oxide particles into an anion exchange resin which has a high capacity to remove NOM from water. The CSIRO in Australia developed the concept of magnetic based resins originally for water softening applications in industry. Subsequently CSIRO expanded the magnetic particle concept with the Sirofloc™ process which is not an ion exchange technology.

The Australian Water Quality Centre (AWQC) in Adelaide had been working on the characterisation of NOM as part of broader studies on the effect of NOM on water treatment. In this work, resins with very good capacity to remove NOM from water were identified and the concept of linking this application (and the resin functionality) with the magnetic concept of CSIRO was suggested. This work has proceeded over some years as a joint development of the AWQC, the CSIRO and Orica (formally ICI Aust.).

The process is designed so that it can be retro-fitted into a conventional water filtration plant. The resin is small (approx. 30 µm) and can be added to the raw water to achieve the desired removal of NOM. The small particle size provides a high surface area for adsorption and so the removal proceeds rapidly with moderate stirring. Contact times of between

10 and 20 minutes can achieve NOM reductions as high as 85–90%. The magnetic properties of the resin promotes aggregation of the resin in the more quiescent conditions in a separation vessel, thereby facilitating resin recovery. The recovered resin is recirculated to the head of the plant for further use in NOM extraction. In this mode of operation, the resin is not heavily loaded with NOM and can be recirculated a number of times and remains effective. A small proportion (5–15%) of the resin flow is diverted to regeneration which is simply achieved with brief contact with brine. The brine can be re-used many times and even recovered if necessary through the use of a specialised reverse osmosis membrane that separates the NOM from the salt solution.

Typical results achieved with MIEX® are shown in Table 5. The advantage of this process is that the resin can be used in turbid water without physical fouling, such as would occur with the use of column systems. The dose rate can be varied readily just as any other chemical material used in water treatment to achieve the desired removal. The NOM removal proceeds rapidly, the resin can be easily recovered due to the magnetic properties and any subsequent treatment can be applied with much reduced impact from NOM. Better final water quality is achieved. The impact of DBP formation is significant, as is the reduction in disinfectant demand. The decay of chlorine in the distribution system is substantially reduced such that it is easier to provide residuals at a lower, more stable level through a much more extensive distribution system than otherwise would be the case.

Table 5 MIEX® – Effect of resin dose on water quality

Resin Dose ML/L	Alum Dose mg/L	Turbidity NTU	Colour HU	DOC mg/L	SDSTHM (µg/L)
0	0	10.7	184	7.0	395
0	70	0.98	18	2.7	130
0.5	50	1.70	28	2.6	144
1	50	1.21	19	2.3	114
2	30	0.76	13	1.8	98
3	20	0.33	9	1.7	87
4	15	0.28	7	1.4	73
5	15	0.21	5	1.1	51

Note: SDSTHM is the simulated distribution system trihalomethane formation

Summary

NOM is a key issue in most, if not all forms of drinking water treatment. There are distinct advantages in understanding the interactions of NOM with treatment processes, the most important being an improved ability to be able to get optimum performance from established facilities. This has become a higher priority need for many water treatment operators to ensure adequate protection from the breakthrough of *Cryptosporidium* oocytes.

In cases where NOM is relatively high in the source water, the removal of NOM as an initial part of the process stream provides many operational benefits while achieving much better water quality. There are circumstances where such an approach is the only way that activated carbon filtration can be used economically. Similar enhancements to microfiltration membrane systems are evident.