Activated Carbon Systems: Can They Keep Up with Proposed PFAS Guideline Levels?

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Abstract

In October 2024, the NHMRC announced its review of the Australian Drinking Water Guidelines for PFAS compounds, including reducing the PFOS guideline from 70ng/L to 4ng/L. Activated carbon is recognised worldwide for its effective removal of various PFAS compounds, in a range of applications.

In Australia, a large number of municipal water treatment plants already have activated carbon treatment options available for taste and odour removal. These include powdered activated carbon (PAC) that is dosed into the raw water, and granular activated carbon filters that are typically operated in the long term as biological activated carbon (BAC) filters, both with and without ozone.

Activated carbon filters in potable water treatment typically remove organics through two mechanisms – adsorption and biological. Initially, when the carbon is virgin, the primary mechanism for organics reduction is adsorption. The length and effectiveness of this initial adsorption stage is dependent on the adsorptive capacity of the carbon and the affinity of the organics to the carbon adsorption sites.

The ability of the carbon to remove organics in the long term is dependent on the biodegradable component of the dissolved organic carbon (BDOC) present in the inlet water stream, whereas refractory compounds such as the PFAS suite of compounds, are solely reliant on adsorption as an effective removal mechanism.

This paper highlights case studies on evaluating the effectiveness of activated carbon treatment options using jar testing, carbon affinity testing, and rapid small scale column tests (RSSCTs), to assist Australian water authorities in addressing future PFAS challenges.

Introduction

Per- and polyfluoroalkyl substances (PFAS) are a class of synthetic chemicals widely used in industrial and consumer products for their resistance to heat, water, and oil. Due to their environmental persistence and potential health risks, PFAS contamination in drinking water has become a growing concern worldwide. In response, the NHMRC is currently reviewing the Australian Drinking Water Guidelines to match the extremely low levels regulated by the US EPA for PFOS from 70ng/L to 4ng/L.

Activated carbon is a commonly used treatment technology in Australia, leveraging its highly porous structure and large surface area to adsorb contaminants - predominantly organics and taste and odour compounds - from water sources. Activated carbon systems can be powdered activated carbon (PAC) or granular activated carbon (GAC) or biological activated carbon (BAC) – both with and without ozone.

Powdered Activated Carbon (PAC): PAC is typically dosed intermittently into the water treatment process, often at the coagulation or filtration stage, to address seasonal contamination events such as algae blooms or specific pollutant concerns such as PFAS. It is particularly useful for short-term PFAS removal but requires continuous replenishment, which may make it less efficient for long-term, large-scale applications.

Granular Activated Carbon (GAC): GAC is used in fixed-bed filtration systems, where water flows through carbon-filled contactors that adsorb contaminants onto the porous surface. GAC filters are commonly implemented for long-term PFAS control in industrial water supplies, offering sustained removal efficiency. However, their effectiveness depends on factors such as adsorption affinity, water matrices (background organics), carbon type, contact time, and bed life (adsorptive capacity).

Biological Activated Carbon (BAC): BAC Biological activated carbon (BAC) is a treatment approach that combines granular activated carbon (GAC) adsorption with biodegradation by microorganisms. While BAC is highly effective for removing organic matter, taste and odour compounds, and some disinfection byproduct pre-cursors, it isNot not considered highly effective for PFAS reduction. The effectiveness of PFAS reduction is still a function of adsorptive capacity as PFAS is not biodegradable.

Ozone + BAC: Ozone is commonly used in conjunction with granular activated carbon filtration to improve bed life and long term organics reduction. The strong oxidising capacity of the ozone breaks down long chain organics and makes them more biodegradable. Ozone and BAC are effective in removing most contaminants of concern from drinking water for long periods of time (15-20 years) however the ozone does not breakdown PFAS and therefore the O3/BAC process is still heavily reliant on the adsorptive capacity of the carbon for its removal.

Results and Discussion

Assessing the Effectiveness of Activated Carbon Processes

The different activated carbon processes can be assessed in lab scale using either the raw water from the WTP (if PFAS is detected) or a spiked sample of raw water (for risk assessment purposes).

Powdered Activated Carbon (PAC)

To best determine if PAC can meet the PFAS guidelines, jar testing is recommended (Figure 1). Jar testing is used to simulate the full-scale plant conditions. Below is a common list of variables:

- Type of PAC
- Dose of PAC (mg/L)
- Location of PAC injection relative to other chemicals
- Type of coagulant
- Dose of coagulant
- Mixing speed and time
- Settling time

After addition of the various chemicals, a subsample is collected, filtered and sent to an external lab for PFAS analysis. From these results the best PAC and dose rate for PFAS removal can be determined.

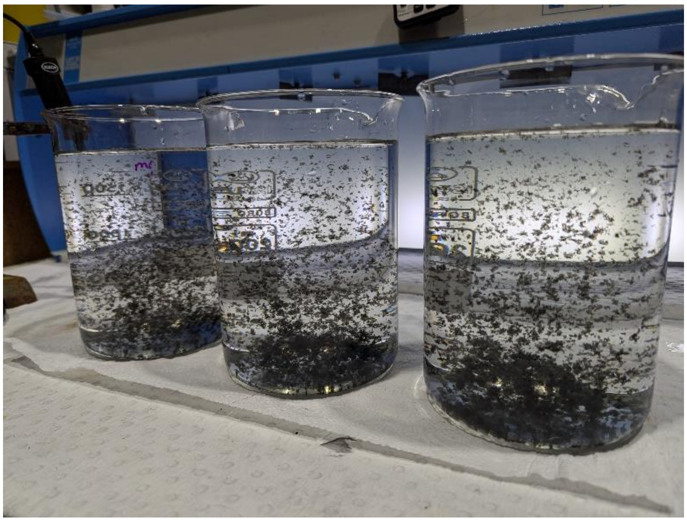

Figure 1– PAC Jar Testing

Granular Activated Carbon (GAC)

GAC effectiveness can be determined in lab scale through two different column tests:

- Lab scale column tests – carbon affinity test
- Rapid small scale column tests (RSSCTs) – bed life determination

The lab scale column test consists of pumping water through a column of GAC (between 4 hours and 4 days) and samples collected every 24 hours. The test is a direct representation of full scale operation (no scaling) and therefore usually does not run for long enough to provide an indication of bed life. It can however determine if the contact time and type of carbon is suitable to remove the PFAS from the water matrix as received. Lab scale column tests can also be used for IEX evaluation.

RSSCTs typically run for 12 – 36 days. They use scaling equations (such as USEPA) to simulate full scale GAC filtration in small scale, allowing 12 days of operation to represent approximately 60 days of full scale operation. This test is designed to determine the bed life of GAC in addition to the adsorptive affinity of the carbon. Due to the scaling required this test requires the feed water to be pre-filtered and there can be no turbidity present in the feed water.

Biological Activated Carbon (BAC)

To assess if the BAC is going to be effective for PFAS reduction a sample of the “in use” BAC is placed in a lab scale column and feed water pumped through in the same way as the GAC lab scale column test.

As the BAC performance for PFAS reduction is dependent on adsorptive capacity, an iodine number test could be used first to determine adsorptive capacity prior to column testing

Lab Scale PFAS Removal with Activated Carbon

PAC Jar Testing

Extensive PAC jar tests were conducted for Activated Carbon Technologies looking at the impacts of activated carbon type (iodine number), dose rate (10, 20 and 50 mg/L), and background organics (low (DOC = 2mg/L) and high (DOC = 7mg/L)) on reduction of different types of PFAS compounds (chain length and molecular weight) and different concentration effects – high (100 µg/L) and low (9 µg/L) PFAS concentrations.

The results of the project are too extensive to report here, however a small section of data is shown in Figures 2 and 3, indicating the impact of iodine number on PFAS removal (Acticarb PS1300 has the highest overall removal capacity) and the selectiveness of long chain PFAS removal over small chain reduction.

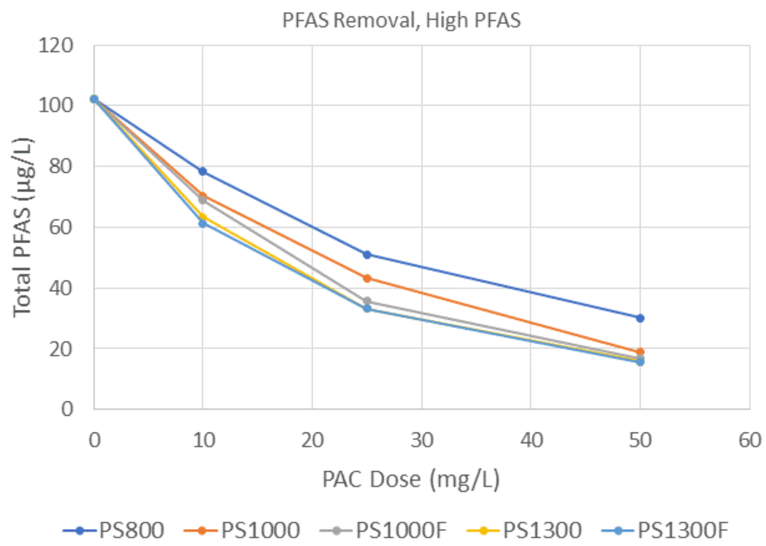

Figure 2– PFAS removal for PFAS removal jar tests. Low and high PFAS feed water, 60 minute contact time

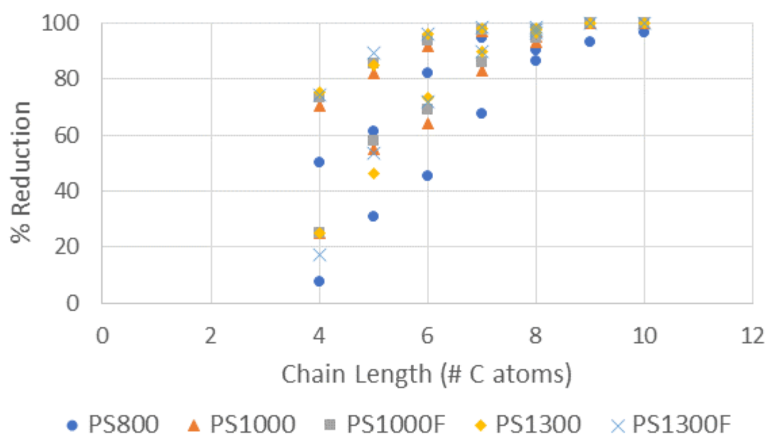

Figure 3 – % Reduction of PFAS molecules as a function of chain length, 50 mg/L dose rate, high PFAS feed water

GAC Lab Scale Column Tests

Lab scale column tests have predominantly been used in industrial applications where interference from organics may minimise the carbon's effectiveness in removing PFAS. Below is an example of a project run by Veolia where industrial water was pre-treated using coagulation/ filtration and then pumped through a lab scale GAC column. Organics and PFAS concentrations were monitored over time to determine the carbons adsorptive affinity for PFAS within this specific water matrix.

Parameter	Veolia WW	Feed	C1 24 hr	C1 48 hr	C1 72 hr
Perfluoroalkyl Sulfonic Acids (µg/L)					
Perfluorobutane sulfonic acid (PFBS)	0.014	0.010	<0.002	<0.002	<0.002
Perfluoropentane sulfonic acid (PFPeS)	0.005	<0.007	<0.002	<0.002	<0.002
Perfluorohexane sulfonic acid (PFHxS)	0.049	0.048	<0.002	<0.002	<0.002
Perfluoroheptane sulfonic acid (PFHpS)	0.002	<0.007	<0.002	<0.002	<0.002
Perfluorooctane sulfonic acid (PFOS)	0.156	0.127	<0.002	<0.002	<0.002
Perfluorodecane sulfonic acid (PFDS)	<0.002	<0.007	<0.002	<0.002	<0.002
Total Organic Carbon (mg/L)	13	39	6	3	3
Chemical Oxygen Demand (mg/L)	28	46	<10	<10	<10
Biochemical Oxygen Demand (mg/L)	8	36	<10	<10	<10

Table 1 – Sample of Lab Scale GAC Column Data

<u>Rapid Small Scale Column Tests (RSSCTs)</u>

There are a number of different RSSCT methodologies available however Research Laboratory Services uses the Constant-Flux (Proportional Diffusivity) Method outlined in the USEPA ICR Manual for Bench and Pilot Scale Treatment Studies. Although RSSCTs are an accelerated test they still require significant volumes of water and time to complete, especially if bed life is to be determined. They also require precise calibration of particle size to maintain proportionality. These factors lead to increased costs.

Table 2 shows a project conducted by a client where raw water was spiked with PFOS and the reduction monitored over 46 days of operation. This raw water had exceptionally low turbidity and low organics, allowing the column to be run without headloss for this extended period.

Parameter	Feed	GAC6	GAC12	GAC18	GAC24	GAC28	GAC34	GAC40	GAC46
Full Scale Equivalent (Days)		**30**	**60**	**90**	**120**	**140**	**170**	**200**	**230**
Sum of PFASs (n=30) (ug/L)	0.044	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Total Organic Carbon (mg/L)	0.8	0.6	0.6	0.4	0.4	0.4	0.4	0.4	0.5
UV254 (Abs/cm)	0.005	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002

Table 2 – Sample of RSSCT GAC Data

Conclusions

There are many variables to consider when assessing if your current activated carbon system can meet the new PFAS guidelines, including:

- Raw water quality
  - Is PFAS present or are you interested in assessing the risk of PFAS contamination in the future? Concentration?
  - Background organics
  - Type of PFAS – long chain or short chain
- Activated carbon
  - Type – adsorptive capacity, surface chemistry

- Contact time
- Dose rate (for PAC)
- Bed life (for GAC)

Although activated carbon is not a cheap treatment option it is commonly available and potentially not as expensive as IEX and RO.

Acknowledgements

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