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Water quality of membrane filtered rainwater

B. Kus[a], Jaya Kandasamy[a]*, S. Vigneswaran[a], H.K. Shon[a], N. Areerachakul[b]

[a]*Faculty of Engineering and IT, University of Technology, Sydney, P.O. BOX 123, Broadway, NSW 2007, Australia*
Tel. +61 (2) 95142558; Fax +61 (2) 95142633; email: jaya.kandasamy@uts.edu.au
[b]*Faculty of Science, Rajamangala University of Technology, Thanyaburi, Bangkok, Thailand*

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ABSTRACT

Although most Australians receive their domestic supply from reticulated mains or town water, there are vast areas with very low population densities and few reticulated supplies. In many of these areas rainwater collected in tanks is the primary source of drinking water. Heavy metals are a concern as their concentration in rainwater tanks was found to exceed recommended levels suitable for human consumption. This paper reports on experimental investigations where rainwater collected from a typical domestic roof in Sydney, Australia was treated in two stages of filtration including granular activated carbon (GAC) as a pre-treatment adsorption filter media and a metallic membrane from Steri-flow Filtration Systems Pty. Ltd. The quality of the treated rainwater was compared against the drinking water standards to determine its suitability as a supplement for potable water supply. The pollutants analysed were heavy metals, total coliform and faecal coliforms, total organic carbon, total suspended solids and turbidity. The results indicate that before treatment, the rainwater already complied with many of the parameters specified in drinking water standards. The metallic membrane performed well in removing suspended particles and heavy metals from the rainwater. The performance of the metallic membrane is greatly improved by the use of pre-treatment such as GAC which was used in this experiment.

Keywords: Rainwater; Membrane filtration; Granular activated carbon; Adsorption; Heavy metal; Nutrient

1. Introduction

Rainwater is recognized as a valuable water resource that can be exploited to provide a sustainable water supply and augment potable water supply in urban areas. Although many Australians receive their domestic water supply from reticulated mains or town water there are vast areas of Australia with low population densities with no reticulated supplies [1]. In many of these areas, rainwater collected in tanks is the primary source of drinking water. Even in areas that are serviced by town mains water, many households, schools, community and commercial centres collect rainwater in rainwater tanks to augment supplies or provide an alternative and sustainable source of water. Widespread water restrictions in recent years in cities such as Sydney, Adelaide and Brisbane have brought to prominence water conservation measures, including the use of rainwater tanks.

Rainwater contains contaminants including particles and micro-organisms. Rainwater harvested from roofs can contain animal and bird faces, mosses and lichens, windblown dust, particulates from urban pollution, pesticides, and inorganic ions from the sea (Ca, Mg, Na, K, Cl, SO_4), and dissolved gases (CO_2, NO_x, SO_x). High levels

* Corresponding author.

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of pesticide are also found in rainwater. Heavy metals have recently become a concern as their concentration in rain water tanks was found to exceed the recommended levels and therefore makes it unsuitable for human consumption [2–5]. Rainwater storage tanks also accumulate contaminants, and sediments that settle to the bottom.

This paper reports on tests carried out where rainwater collected from a domestic roof in Sydney, Australia was treated in two stages of filtration including Granular Activated Carbon (GAC) as a pre-treatment adsorption filter media and a metallic membrane filter (Steri-flow). The quality of the treated rainwater is compared against the Australian Drinking Water Guidelines (ADWG) [6] to determine its suitability as a supplement for potable water supply. The pollutants analysed were heavy metals, total coliform and faecal coliforms, total organic carbon, total suspended solids and turbidity.

2. Experimental

2.1. Collection of raw rainwater

The Sydney Basin is a classic "closed" geographical basin, bounded by high ground to the south, west and north, and by the temperature differential between land and ocean on the eastern side as shown in Fig. 1. From early morning, air pollution generated from primary sources (industry, road transport, etc.) collects over the Sydney basin. Onshore afternoon sea breezes, typically from the north-east, pick-up this air pollution and smog and concentrate it in the south western corner of Sydney. The air quality in Sydney is worst in the South Western suburbs and it is here the sampled rainwater tank is located as shown in Fig. 1. Detailed sampling and experiments were previously carried out at nine other rainwater tanks located in different parts of Sydney and one in Wollongong, a town south of Sydney, New South Wales, Australia, Fig. A, [7]. The rainwater tank selected to supply water for this study had the worst rainwater quality. The rainwater tank was 1 year old and collects water off a concrete tiled roof of a 30 year old house. The house is located near an industrial area and a freeway. The tank is made from polyethylene and is plumbed using PVC fittings from the gutter to the tank. Two batches of rainwater were collected for testing and analysis. The first batch was first flush roof runoff and was polluted. The second batch was collected after the first flush and was less polluted.

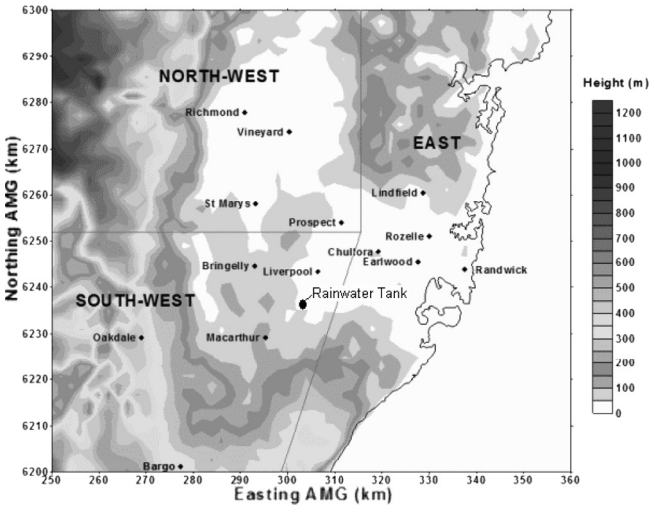

Fig. 1. Location of rainwater in relation to the Sydney Basin [8].

2.2. Laboratory water quality analysis

Detailed laboratory analysis was carried out on rainwater in the rainwater tank and the effluent of the filtration system to determine the quality of the treated rainwater and how it compares against drinking water standards (AWDG). The pollutants analysed and testing methods are summarised in Table 1. TOC was measured by using the Dohrmann Phoenix 8000 UV-persulphate TOC analyser equipped with an autosampler. All samples were filtered through 0.45 μm membrane prior to the TOC measurement. Thus, the TOC obtained was, in fact, dissolved organic carbon (DOC) values.

2.3. Granular activated carbon (GAC) filter media

The filter media used in the experiments was granular activated carbon (GAC) supplied by James Cumming, Australia. The properties of the GAC are shown in Table 2.

2.4. GAC filter pre-treatment

The role of the adsorption media as a pre-treatment to membrane filtration is important as it is relatively affordable and easy to clean or replace compared to fouling of membrane filtration processes. The GAC filter media can substantially extend the life and operation of a membrane by removing suspended solids and by providing pre-treatment of heavy metals, organics, colours, and odours. This can allow the membranes filtration process to achieve higher removal rates of any remaining heavy metals, organics, pathogens and some virus for a longer period of time without premature fouling resulting in costly additional physical or chemical treatment.

Pre-treatment experiments were carried out to analyse the performance of GAC at treating the raw rainwater collected in the rainwater tank. The raw rainwater was passed through the filter columns to analyse the effectiveness of GAC at different flow rates. Two filter columns were used for this experiment to accommodate the various flow rates through the GAC (Table 3). Water samples for analysis were collected from the raw rainwater and the effluent. The effluent water from the pre-treatment experiments was collected for further experimental analysis through the metallic membrane.

Table 1
Water quality parameters and measurement methods

Parameter	Measurement method [9]
Heavy metals (aluminium, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver and zinc	APHA 3120 ICPMS — Inductively coupled plasma-mass spectrometry
Chloride	APHA 4500-Cl^- – G – Mercuric thiocyanate flow injection analysis
Nitrate	APHA 4500 NO_3^-– F – Automated cadmium reduction method
Nitrite	APHA 4500 NO_2^-– B – Colorimetric method
Mineral salts (calcium, magnesium, potassium, sodium and sulphate)	APHA 3120 ICPOES – Inductively coupled plasma – optical emission spectrometry
pH	APHA 4500-H^+ –Electronic method
Ammonia	APHA 4500 NH_3-N –Flow injection analysis
Orthophosphate	APHA 4500 P-G – Flow injection analysis for orthophosphate
Conductivity	APHA 2510-B – Laboratory method
Water hardness	Calcium and magnesium calculation
Turbidity	APHA 2130 – Nephelometric method
Total suspended solids	GFC equiv. filter – APHA 2540 – D – Total suspended solids dried at 103–105°C
Total dissolved salts	Calculation using EC x 680
Bicarbonates	Total alkalinity – APHA 2320 – Titration method

* APHA - American Public Health Association

Table 2
Physical properties of GAC

Specification	Estimated value
Iodine number, mg/(g.min)	800
Nominal size, m	3×10^{-4}
Maximum moisture content, %	5
Bulk density, kg/m^3	748
BET surface area, m^2/g	748

Table 3
Specifications of GAC filter columns

	Column 1 (FC1)	Column 2 (FC2)
Column height, mm	500	500
Internal diameter, mm	20	20
Media height, m	0.3	0.3
Flowrate, m/h	1	5

2.5. Filter membranes

Membrane filtration experiments were carried out using a metallic membrane (Steri-flow filtration system) (Table 4). This system was tested in a cross-flow configuration of filtration. The membrane had a surface area of 0.03 m^2 and pore size of 0.3 μm.

Table 4
Physical properties of filter membranes

Name	Metallic membrane (MF A)
Manufacturer	Steri-flow filtraiton system
Material	Metal — stainless steel
Pore size, μm	0.3
Membrane dimensions, mm	450 long, 20 dia.
Filter area, m^2	0.03
Method	In to out

2.6. High flow filtration flux decline

Experiments were configured to test the metallic membrane for flux decline and pollutant removal performance using a high pressure pump. The influents used in these experiments were from the raw rainwater and from the GAC pre-treated effluent. Water analysis samples were collected after passing through the membrane at the beginning and nearing the end of each experiment for analysis.

3. Results and discussion

3.1. Raw rainwater quality

The concentration of pollutants in the two batches of raw rainwater collected from the rainwater tanks are shown in Tables 5 and 6. The rainwater was collected during a rainfall event that was preceded by 15 dry days. The total rainfall duration was 25 mm and the average intensity was 13 mm/h. Samples for batch 1 were taken directly from the downpipe from the gutter before the first flush system. Samples for batch 2 were taken after the first flush system. The water from the majority of rainwater tanks comply with the heavy metals tested. The concentration levels of aluminium, iron, lead, zinc all showed very low to negligible concentration of less than 0.066 mg/L.

The ADWG has a recommended limit of turbidity to 5 NTU [2]. The turbidity of the two samples collected from the rainwater tank was variable. One sample had a turbidity of 43.5 (batch 1) and the other of 3 (batch 2), the latter being below the ADWG limit. The variability is due to how dirty the roof was before it rained, which is generally dependent on the number of dry days preceding the rainfall event and whether the rainwater sample included the first flush (batch 1) or the sample was collected after the first flush (batch 2). The concentration of total suspended solids showed a similar trend to turbidity.

The concentration of total organic carbon in the samples collected from the rainwater tank was both 1.1 mg/L. This is higher than the ADWG limit of 0.2 mg/L.

The total and faecal coliform counts in the samples of rainwater were relatively high at between 410–540 and 115–175 respectively. The ADWG recommended limit for total and faecal coliform is zero [9].

Overall, the water collected in the rainwater tanks generally complies with the standards for most parameters specified by ADWG except for a few individual parameters. The majority of parameters tested were comparable to potable water.

3.2. GAC pre-treatment and membrane filtration

The flux decline measured during experiments is shown in Figs. 2 and 3. The flux decline was substantially prolonged for the metallic membrane by pre-treating the raw rainwater with GAC. This will allow extended durations between required backwashing for membrane cleaning.

The pollutant removal from the metallic membrane filtration, GAC, and pre-treatment of GAC followed by metallic membrane filtration is shown in Tables 5. Also shown for the various parameters that were measured are the Australian Drinking Water Guidelines (ADWG) [2] safe limits and the detectable limits.

Metallic membrane filtration and GAC are both effective in removing suspended solids and turbidity. When applied in combination (pre-treatment of GAC followed by metallic membrane filtration) the pollutant concentration is reduced to below detectable limits. TOC is mainly removed by GAC (Table 5).

The removal of total and faecal coliform was effective with metallic membrane filtration which removes the coliforms to below detectable limits. To achieve drinking water standards, a tertiary stage treatment such as chlorination or UV is recommended to reduce total and faecal coliforms.

Heavy metals concentrations in raw rainwater are all below ADWG specified limits. Metallic membrane

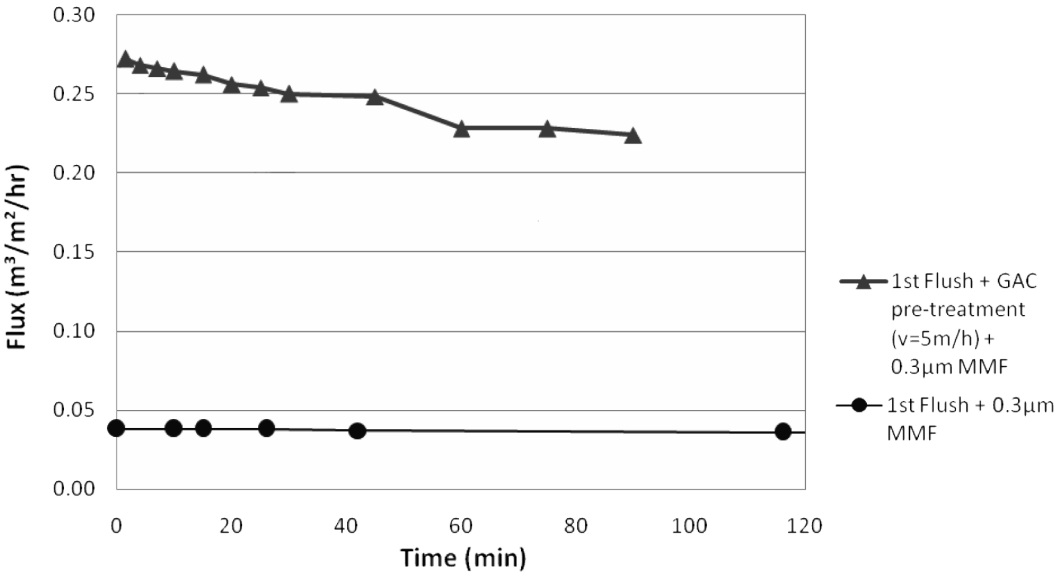

Fig. 2. Flux decline of metallic membrane using rainwater batch 1 (includes first flush and relatively polluted rainwater).

Table 5
Summary of results from experiments

	ADWG (2004)	Detectable limits	Batch 1				Batch 2			
			Raw water	MMF	GAC @ 5 m/h	GAC @ 5 m/h + MMF	Raw water	MMF	GAC @ 5 m/h	GAC @ 5m/h + MMF
Total suspended solids, mg/L	NA	0.5	16.5 (16.5–16.5)	ND*	ND*	ND*	2.0 (1.5–2.5)	ND*	ND*	ND*
Turbidity, NTU	5	0.2	43.5 (41.0–46.0)	1.15 (0.3–2.0)	8.5 (6.0–11.0)	ND*	3.0 (3.0–3.0)	0.5 (0.5–0.5)	ND*	ND*
Total coliforms, cfu/100 Ml	0	10	410 (350–470)	ND*	NM	ND*	540 (460–620)	ND*	60 (40–80)	ND*
Faecal coliforms, cfu/100 Ml	0	10	175 (160–190)	ND*	NM	ND*	115 (90–140)	ND*	ND*	ND*
Aluminium, mg/L	0.2	0.001	0.0235 (0.019–0.028)	0.005 (0.005–0.005)	0.023 (0.015–0.027)	0.005 (0.005–0.005)	0.0285 (0.028–0.029)	ND*	0.028 (0.027–0.029)	ND*
Iron, mg/L	0.3	0.001	0.0665 (0.057–0.076)	0.011 (0.006–0.016)	0.018 (0.016–0.020)	0.010 (0.003–0.021)	0.038 (0.032–0.044)	ND*	ND*	ND*
Lead, mg/L	0.01	0.001	0.0015 (0.001–0.002)	ND*	ND*	ND*	0.005 (0.005–0.005)	ND*	ND*	ND*
Zinc, mg/L	3	0.001	0.0125 (0.012–0.013)	0.012 (0.003–0.021)	0.004 (0.003–0.005)	0.0035 (0.003–0.004)	0.021 (0.020–0.021)	0.008 (0.003–0.013)	0.009 (0.008–0.010	0.005 (0.004–0.006)
Total organic carbon, mg/L	NA	0.2	1.100 (1.100–1.100)	0.85 (0.700–1.000)	ND*	ND*	1.10 (1.150–1.005)	0.750 (0.700–0.800)	ND*	ND*

MMF denotes metallic membrane filter
ND* denotes pollutant concentration below detectable limits.
NM denotes not measured

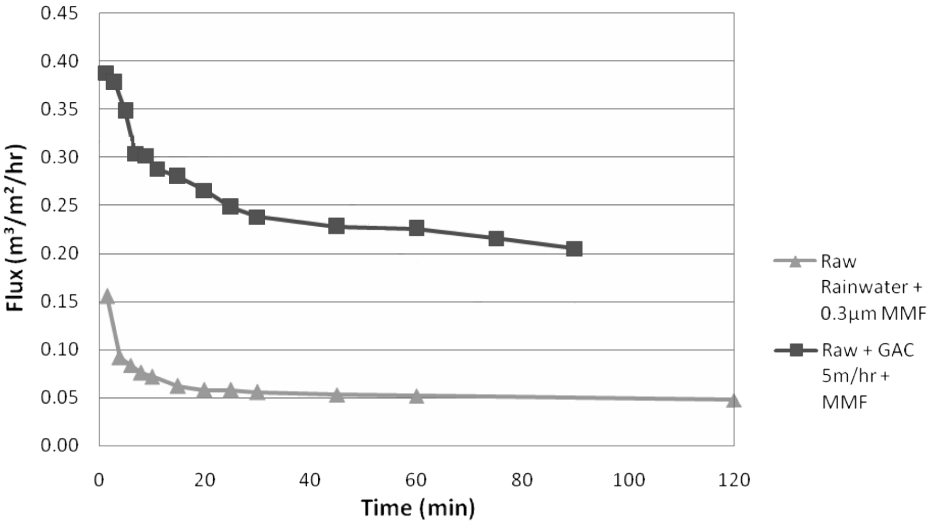

Fig. 3. Flux decline of metallic membrane using rainwater batch 2 (with less polluted rainwater).

filtration and GAC are both effective in removing heavy metals and in many cases the heavy metal concentrations reduced to below detection limits (Table 5). Importantly, metallic membrane filtration and GAC were both effective in removing lead to concentrations below detectable limits. Both were also effective in removing iron (Table 5). Aluminium is predominantly removed by metallic membrane filtration. GAC was not effective in removing aluminium.

4. Conclusion

Metallic membrane filtration and GAC are both effective in removing suspended solids and turbidity. TOC is mainly removed by GAC. Heavy metals concentrations in raw rainwater are all below ADWG specified limits. The performance of the metallic membrane was greatly improved by the use of pre-treatment such as GAC which was used in this experiment. In particular the GAC filter was instrumental in increasing the flux and resulted in lower flux decline.

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