COLOUR IN ROOF WATER PREVENTING THE REUSE AND HOW TO REMOVE THEM

Ropru Rangsivek, Ph.D.[1, 2]

[1]Lautrec Technology Group, Takapuna, Auckland, New Zealand
[2]Former Water Technology Specialist at Grundfos A/S, Bjerringbro, Denmark

ABSTRACT

Increased urbanisation throughout the world has led to an increase in the likelihood of flooding. Therefore, stormwater management has become an important issue. In the context of Auckland, New Zealand, stormwater is managed mainly to prevent nuisance and damage to other properties downstream. The installation of a detention tank is a common means to manage the stormwater flow from site. A dual purpose tank is also common especially in Stormwater Management Control Area, where the receiving network/watercourse is particularly sensitive to discharge. A dual purpose tank detains stormwater before slowly releasing it downstream, thus reducing peak flow issues. Retention volume is captured for the purpose of reuse, e.g., for laundry and toilet flushing. However, the question has been raised whether these stormwater tanks do serve their designed purposes. We have found several cases in which the tank owners were reluctant to use stormwater for toilet flushing and laundry. This reluctance was due to aesthetic reasons, specifically the dissolved colour present in the water that cannot easily be removed. They therefore turn off the tap once the Producer statement (PS4) has been signed off. In this work, case studies of how dissolved colour in water preventing the utilization of the harvested water will be presented. Furthermore, a detailed investigation on removal of colour from the water is demonstrated using ozonation and adsorption filters. Following the test, a pilot scale setup for rainwater reuse was installed in a building to monitor long term performance. The results will be shown during the presentation and are not included in this paper. It is the aim of this work to improve the quality of water and gain a better understanding of people's perceptions toward reusing the harvested rainwater.

KEYWORDS

Dual purpose tank; colour in rainwater; water treatment

1. INTRODUCTION

Stormwater management has grown increasingly in importance due to urbanization throughout the world. Increases of impervious areas, due to development has led to an increased frequent of flooding. Stormwater management has been used to mitigate this. At the same time, the water thus captured has become an additional source of water supply. Particularly in water scarce countries, capturing stormwater for reuse within buildings is recognized as a means to reduce stress on water supplies.

In Auckland, New Zealand, a dual-purpose tank is a common solution. This is especially the case in the Stormwater Management Area Control where the ratio of impervious to pervious area is high. A dual-purpose tank detains stormwater before slowly releasing it downstream, thus mitigating peak flow. In addition, a general requirement is that 5 mm of stormwater shall be captured for reuse purpose. The retained rainwater may be used for toilet flushing and laundry. This can be accounted for a total saving of 60-70% of water consumption in households.

However, the question has been raised whether these stormwater tanks do serve their designed purposes. We have found several cases in which the property owners were reluctant to reuse stormwater as per design for toilet flushing and laundry. This was mainly due to aesthetic reasons, specifically solids and colour present in the water. Therefore, property owners tend to turn off the tap once the Producer statement (PS4) has been signed off. This observation is supported by a market survey of the tank owners in Australia, Belgium, Denmark, and Germany where tank users experience a long term miss-colouring of clothes and O-ring in the toilet (Rangsivek, 2011).

The ”dissolved color” in rainwater is mainly due to the natural organic matter (NOM) originating from leaves and debris, which are not always efficiently removed by the first flush diverter. Studies on colour removal from roof runoff are rare. Studies of NOM removal were mostly done for natural surface water (e.g., Genz, 2005). Furthermore, enquiries on rainwater focused primarily on the removal of metal and microbial contaminations (Foster, 1996; 1998; Steiner, 2003; Lye, 2009; Rangsivek, 2010). Therefore, this paper aims to investigate the performance of colour removal to improve the users’ perception toward water reuse. Laboratory studies of ozonation and filtration through adsorption media were conducted. Following the test, a pilot scale setup for rainwater reuse was installed in a building to monitor long term performance. The results will be shown during the presentation and are not included in this paper.

2. MATERIAL AND METHODOLOGY

2.1 RAINWATER

Rainwater used for the experiments was collected from the Grundfos Technology Center building in Bjerringbro, Denmark, during August-November 2011 as an event mean concentration. The water has a light yellowish colour. Colloids and particles agglomerated and settled at the bottom of the tank. Oak leaves were added to the collected water for 2-3 days to increase the colour of the rainwater for experimental purposes. Tap water from the same building was used as a controlled sample. The characteristics of tested waters are shown in table 1.

Table 1 Characteristic of water tested in this work

Parameters	pH	Cond. [µS/cm]	TOC [mg/L]	UV254 [/cm]	UV436 [/cm]	SUVA [L/mg.m]
Tap – Bjerringbro	7.4	600	1.3	0.033	0.003	2.5
Rainwater*	6-7	60-80	1.6	0.03	0.003	1.8
Colored rainwater (with Oak Leaves)	6-8	60-80	9-11.7	0.38	0.037	3.2

2.2 LABORATORY STUDY

2.2.1 OZONATION EXPERIMENT

The study involves two technologies for removal of colour, namely ozonation and media filtration. The ozonation experiment was conducted using a batch and a flow-through system. In the batch system, a fixed volume of rainwater was added into 2@10cm H x 60 cm L Plexiglas columns. Ozone, produced by a 300 mg h^{-1} ozone generation (Gemke Ozonetech, DE), was injected into the columns via a bubble stone at a constant rate of 1 L min^{-1}. Water samples were taken from 6 small tubes equipped along the length of the columns allowing the determination of kinetic removal of colour and organic carbon. The tests were configured as shown in Table 2. An attempt was also made to find the effect of bubble size on colour removal by ozone.

Table 2 Ozone experiment configuration

Parameters	Volume [L]	Gas flow [L/min]	O_3 Conc. [mg/h]	Contact time [min]
BatchTest[1] (Aeration/Ozonation)	4	0 or 1	0 or 300	0-60
Continuous test[2]	8	1	300	60
Small bubble size[3] [~1mm]	8	1	300	30

[1]where fixed volume of water is continuously aerated/ozonated; [2]where ozonation is injected under flowing of water through the column at different rates, [3] a special pump is used to produce smaller bubble as compared to using bubble stone

2.2.2 ADSORPTION EXPERIMENT

In the adsorption experiments, four materials were tested including, (1) Sand (2) Granular Activated Carbon (Chemivon, DK) (3) Granular Ferric Hydroxide (GEH Wasserchemie, DE) and (4) MIEX ion exchange Resin (Orica, AUS). The test was conducted in equilibrium batch and column tests in order to determine the adsorption capacity of different media, and to assess their performance over the flow-through conditions, respectively.

Equilibrium Test

A varying dose of media (0-1.5 g L^{-1}) is equilibrated in a set of model runoff volumes (50mL) for 24-48 h. pH and conductivity were initially set to 6.0 and 200 mS cm^{-1} using NaOH, respectively. The test was conducted at room temperature. Subsequently, after the test, water samples were filtered using glass filters and analyzed for total organic carbon (TOC), UV_{254}, color (UV_{436}), pH and conductivity.

Column Test

Four columns containing sand, GFH, GAC, MIEX were configured in parallel. Unless otherwise stated, columns (2.5 cm diameter, 25 cm length) containing the fixed mass of media were employed. GAC and GFH were supported by sand at both ends of the columns whereas MIEX was run in fluidized configuration.

The breakthrough column test was carried out by feeding simulated rainwater into the columns under the same conditions, using an Ismatec peristaltic pump (Switzerland) with a 2.79 mm Tygon tube in an up-flow mode. The water was fed

at a different speeds corresponding to 1-30 min contact times. Water samples before and after the columns were measured for colour removal efficiency.

A preliminary study showed that the breakthrough takes place quickly, and thus, a sequential configuration was used. In this test, water is continually run through the 1st stage of ozonation and the effluent is then fed into the adsorption column simultaneously. Water samples were taken before ozonation, after ozonation and at the outlet of the adsorption columns. The experiment was performed at room temperature.

2.3 ANALYTICAL METHODS

Water samples were measured for pH, ORP, Conductivity (METTLER TOLEDO handheld meter, DE). TOC was measured by non-purgable organic carbon with thermal-catalytic oxidation using a high-TOC analyzer (Shimazdu, JP). Colour was measured by means of a UV/VIS spectrometer. The SUVA value is calculated by UV254/TOC and represents the quantitative measurement of aromatic compounds in the NOM (Chi and Amy, 2004). Selected samples were measured by Liquid chromatography-organic carbon detection (LC-OCD) following the method described by Huber and Frimmel (1996).

3. RESULTS AND DISCUSSION

3.1 OZONATION

Four weeks storing of rainwater without an external input of treatment reduces colour of rainwater by 38% (from UV_{436} = 0.034 to 0.02 cm $^{-1}$ as compared to tap water UV_{436} of 0.003 cm $^{-1}$). The TOC reduces from 11.7 to 8.7 mg L^{-1} corresponding to a slight increase of SUVA from 3.7 to 4.1, indicating that the non-humic fraction is partly removed. A 1 L min^{-1} air injection for about 1 hour shows an insignificant removal of colour, $UV_{254,}$ and TOC (Fig.1). over 65% removal of UV_{436} and 53% for UV_{254} could be achieved by ozonation within 1 h contact time. In the ozonation process, the chromophore group of compounds (double and triple bounds) is attacked by ozone resulting in the loss of aromaticity and depolymerization. This was demonstrated by the reduction in SUVA from 3.7 to 1.7 indicating humic substance has been transformed into smaller molecules, possibly to lower molecular weight acids.

In the continuous experiment, the removal kinetics of colour by ozonation was found to follow a first-order-rate equation (e.g., $C_t = C_0\ e^{-kt}$). Calculation shows the $t_{1/2}$ ($t_{1/2}$ = ln2/k, k is the coefficient from first-order rate kinetic) for colour removal by ozonation and by aeration are 39 min and 990, respectively. Smaller

bubble size (~ 1 mm at normal air, temperature 24-25 C, Gas flow 1 Lm^{-1}) was found to enhance the process with a 10% increases in removal efficiency with a $t_{1/2}$ of 30 min. The enhanced removal efficiency was possibly due to a higher internal pressure that will increase the mass transfer of ozone into the water. the bubble size from 1 mm to 1 µm reduces the up-flow velocity of bubbles from 100 mm/s to about 3 log magnitudes according to Li (2006),

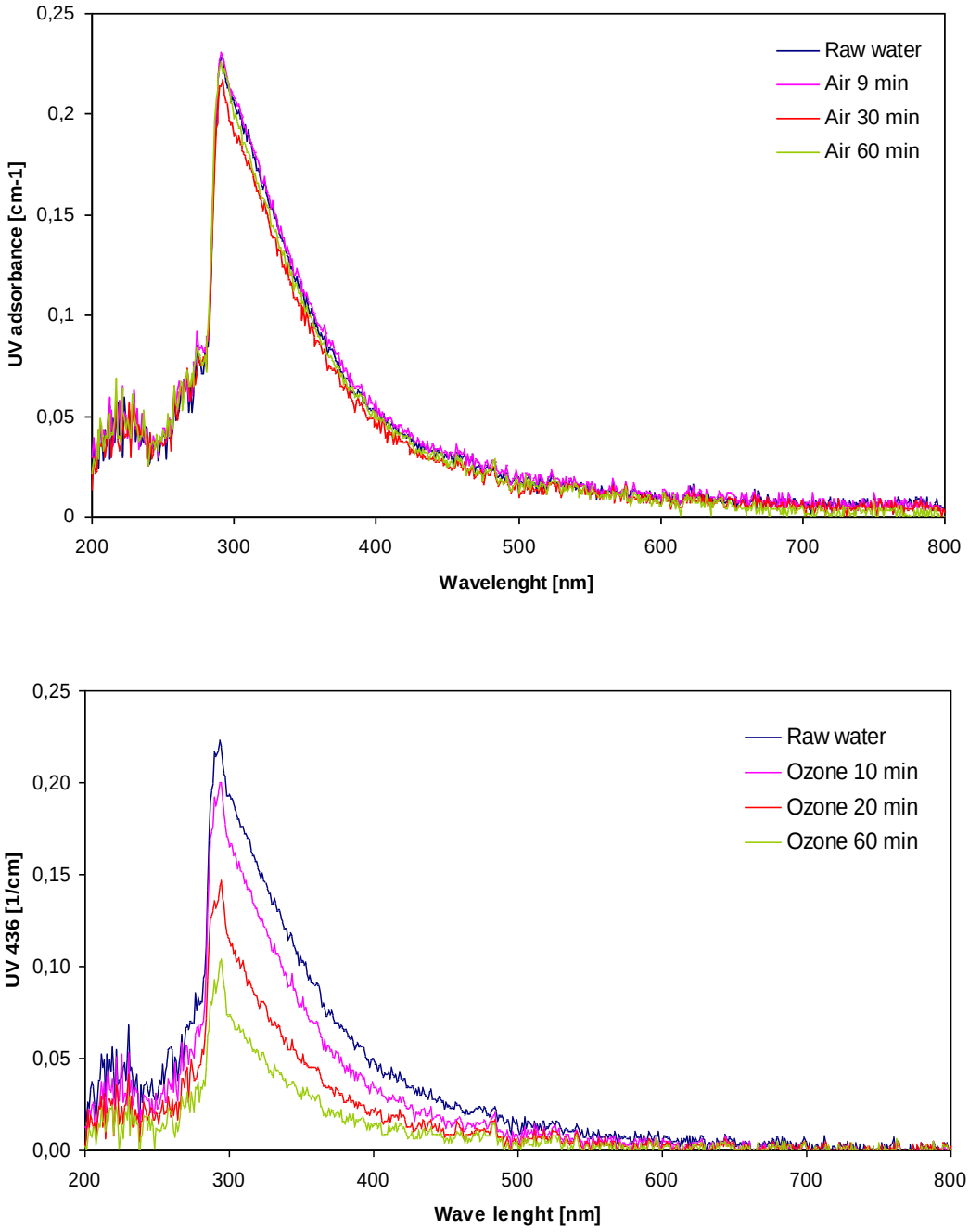

Figure 1 UV spectra of water after aeration and ozonation

The mass balance calculation shows the removal of 10% DOC and 40% of UV adsorption could be achieved with an ozone loading of 1 mg O_3/mg DOC. Schumacher (2005) reported a 90% removal of UV_{436} of membrane bioreactor permeate at the doses of 3 mg O_3/mg DOC. A further dose of ozone will lead to more biodegradable organic water, due to the transformation of high molecular weight (MW) to low MW and neutrals such as carboxylic acids, alcohols and aldehydes, and complete mineralization of the carbon compounds.

3.2 MEDIA FILTRATION

Figure 2 illustrates the adsorption isotherm of total organic carbon removal for the tested materials. Colour of water was removed completely after the experiment. With a contact time of 36 h, MIEX has the highest equilibrium loading of 50 mg g^{-1} at 3 mg L^{-1} equilibrium concentration. This is about 10 times higher than that of GAC. On the contrary, GFH has a low adsorption capacity while DOC removal by sand is minimal. The reason for low NOM removal by GFH is presumably due to the smaller surface area of the test material per mass basis. The non-removable DOC was approximately 2 mg L^{-1} for MIEX and GFH but 0.5 mg L^{-1} for GAC. MIEX has probably more affinity toward large MW compounds, whereas both micro and macro pore size that can adsorb both small and large molecules are distributed for the GAC medium.

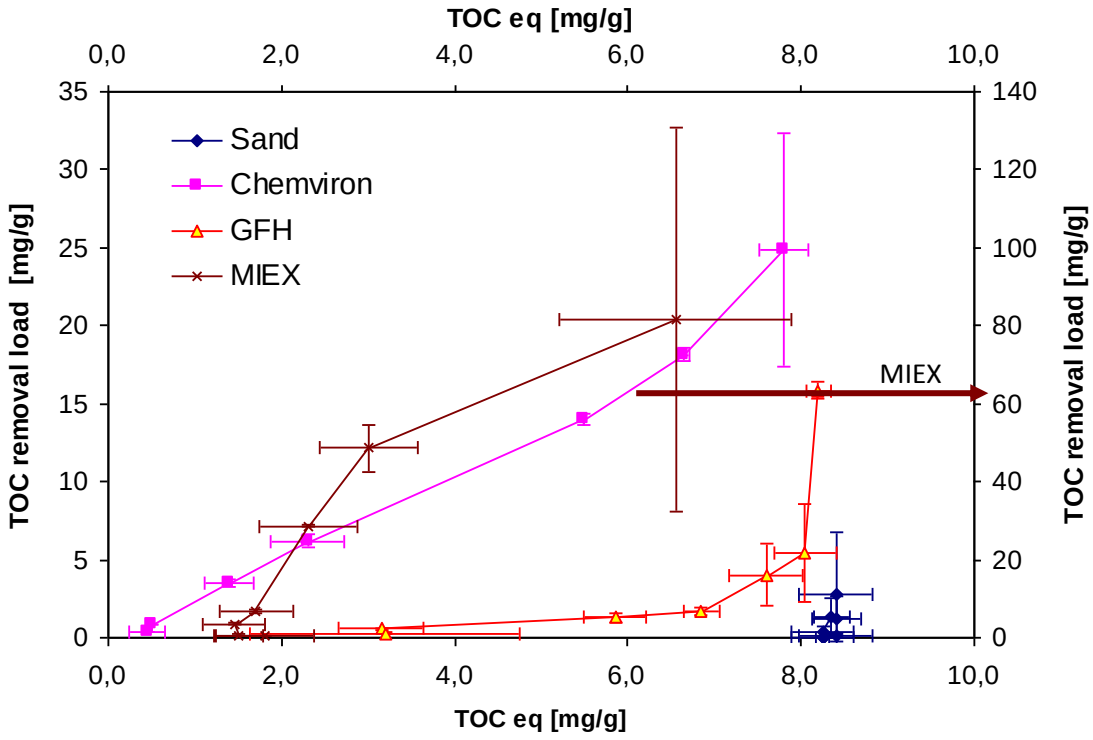

Fig. 2 Adsorption isotherm of TOC removal by different media

Roof runoff NOM mainly contains high molecular weight compounds of polysaccharide and humic fractions. The LC-OCD shows that MIEX removes mainly the charged hydrophobic content whereas uncharged polysaccharide and low molecular weight hydrophilic were not removed. This corresponds well with the reducing of the SUVA value. Rangsivek (2010) found that iron oxide-based sorbent removes preferentially the polysaccharide and charge humic fractions. GAC remove not only high MW fraction but also building block, and low molecular weight fractions (Haberkamp, 2007). MIEX was reported to target the large and medium-size MW compounds.

The effect of empty bed contact time (EBCT) on the colour removal by media filtration was assessed using a column test, where rainwater is fed into columns containing a fixed amount of adsorptive media. According to the results shown in Figure 3, MIEX shows the best performance while GAC and GFH have similar removal efficiency. The removal of colour by adsorption is fast, and there is an insignificant impact of flowing speed.

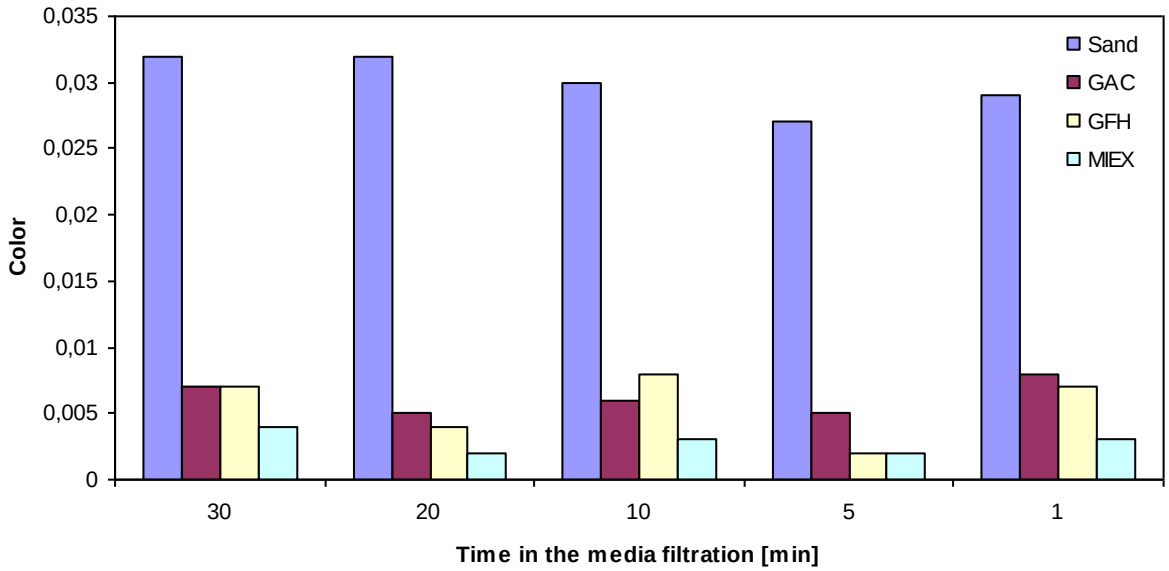

Figure 3 Effect of EBCT on Color by different media

3.3 INTEGRATED PROCESSES

Based on the ozonation and adsorption tests, a further experiment was to conduct a two steps treatment, where rainwater is firstly pre-treated using ozone at 1 hour contact time. Subsequently, the ozonated water is then fed into the adsorption columns with 5 min EBCT. The experiment was conducted for over 4000 Bed Volume Treated (BVT) and the results of the test are shown in Figure 4.

After ozonation, color was found to reduce from about 0.050 to about 0.035 cm^{-1}, accounting to about 50-60% removal efficiency. Visual inspection of ozone-

treated effluent shows a constant light-yellow color with about 4 times UV_{436} higher than that of tap waters. The colour of the water is further significantly reduced during the adsorption process. MIEX was found to be highly efficient in the removal of color down to tab water's level (Fig. 3). The performance of GAC and GFH were inferior to that of MIEX, being less impacted by influent water quality. GFH and GAC show similar performance over the run, even though GAC has a much higher surface area indicating that the hydrophobic effect is less important than charge. In comparison, the sand column cannot remove color. The removal of UV_{254} and TOC removal follows a similar trend to that of UV_{436} in all cases. MIEX removed TOC to about 80% down to 2 mg L^{-1}, a similar range to Tap water. The Breakthrough of all columns was not exhausted over about 4000 BVT. This was due to the biodegradation of NOM in the feed water during storage taken place after the ozonation that reduces the inlet concentration.

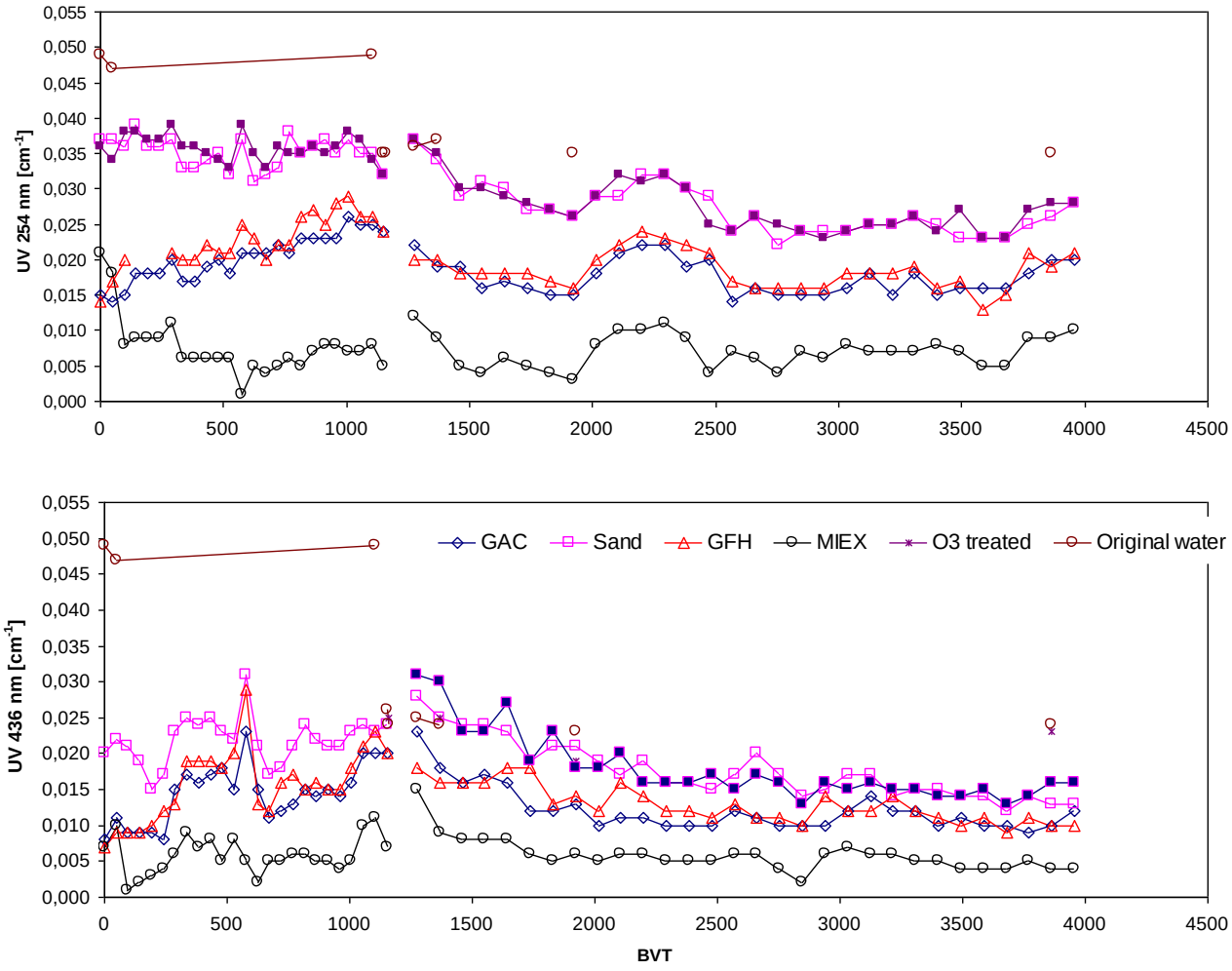

Figure 4 Breakthrough of UV_{254} and UV_{436} from the continuous test

Table 3 summarizes the concentration of TOC, UV, and SUVA of the water samples before and after the experiment. Mass balance calculation over the

entire breakthrough curves shows that GAC, GFH, and MIEX remove 888 mg, 660, 1151 mg TOC with the loading capacity of 13.1, 9.7, 16.9 mg g^{-1} of media, respectively.

Table 3 Summary of concentration in two-step treatment: O_3 and media filtration.

	TOC [mg/L]	UV_{254}	UV_{436}	SUVA
Original sample	988-12.6	0.036-0.038	0.024-0.027	3.62-3.73
After Ozonation	9.45	0.022	0.006-0.017*	2.49
Sand	8.87	0.027	0.017	3.25
GAC	4.65	0.018	0.012	3.88
GFH	5.82	0.018	0.013	3.22
MIEX	3.31	0.007	0.006	2.04

4. SUMMARY AND OUTLOOK

In this study, the method for removal of colour from rainwater has been demonstrated. Two technologies were considered namely, ozonation and adsorption processes. Based on the results, O3 proves to be efficient for the removal of color from rainwater, where up to 65-76% removal of color could be achieved with 1 h contact time. However, complete removal of colour and TOC is not recommended solely by ozonation due to the slow removal rate and high energy consumption. The adsorption techniques were found to be efficient providing a fast kinetic removal. The treatment of colour by adsorption alone will result in rapid exhaustion of the media. Therefore, a two steps treatment having ozonation as a pre-treatment and an adsorption filter as a polishing step is recommended. In view of the application, a pilot scale was established as a demonstration case in an educational building. It was run and monitored for colour and the perception of people was recorded and found to increase satisfaction and perception of people toward using rainwater for the toilet flush. The results of the pilot scale test will be shown during the presentation and not included in this paper. The technology can be applied for the residential and commercial buildings where rainwater reuse is implemented.

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