Australian Water Recycling
Centre of Excellence

Demonstration of robust water recycling: Pathogen log reduction value table

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Australian Water Recycling Centre of Excellence

S. Gray, J. Zhang, A. Knight, P. Scales and K. Northcott
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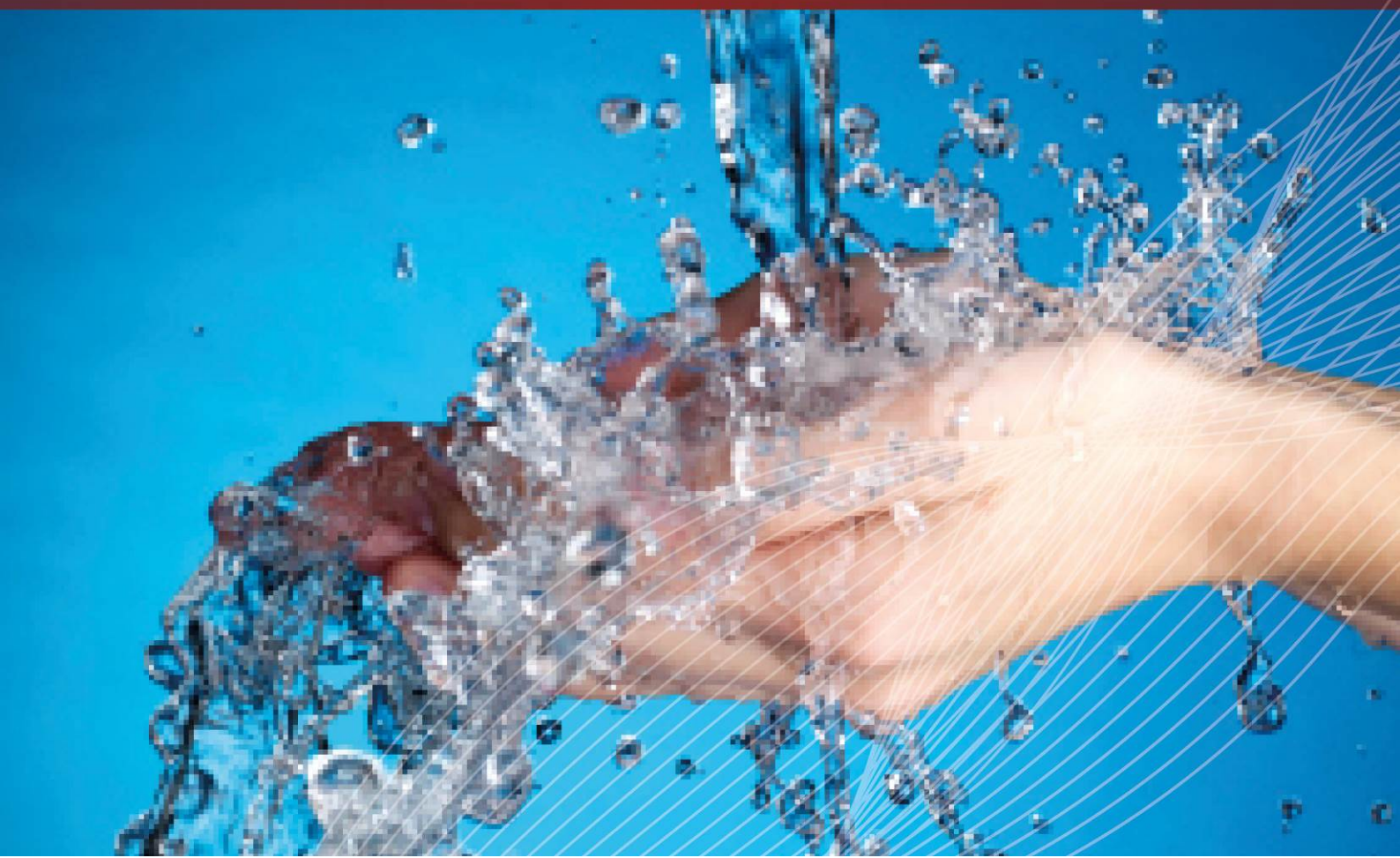

Demonstration of robust water recycling: Pathogen log reduction value table

Project Leader

Prof Stephen Gray
Victoria University
Werribee Campus
PO Box 14428
Melbourne, Victoria, 8001, AUSTRALIA
Telephone: +61 3 9919 8097

Partners

Victoria University
University of Melbourne
Australian Antarctic Division
Veolia
AECOM
TasWater
Coliban Water
Curtin University

Contact: Prof Stephen Gray stephen.gray@vu.edu.au

About the Australian Water Recycling Centre of Excellence

The mission of the Australian Water Recycling Centre of Excellence is to enhance management and use of water recycling through industry partnerships, build capacity and capability within the recycled water industry, and promote water recycling as a socially, environmentally and economically sustainable option for future water security.

The Australian Government has provided $20 million to the Centre through its National Urban Water and Desalination Plan to support applied research and development projects which meet water recycling challenges for Australia's irrigation, urban development, food processing, heavy industry and water utility sectors. This funding has levered an additional $40 million investment from more than 80 private and public organisations, in Australia and overseas.

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TABLE OF CONTENTS

Table 1: Claimed and Achievable LRVs for Unit Processes

Process	LRV					
	Virus		Bacteria		Protozoa	
	Claimed	Credible	Claimed	Credible	Claimed	Credible
MBR	2	3	2	4	2	4
Ozone	2	4	2	4	0	0
Ceramic MF	1	4	1	4	4	4
Biologically Activated Carbon (BAC)	0		0		0	
Reverse Osmosis	1.5	4	1.5	4	2	4
Ultra violet disinfection	4	4	4	4	4	4
Calcite Filter	0		0		0	
Chlorination	4	4	4	4	0	0
Total	**14.5**	**23**	**14.5**	**24**	**12**	**16**
Required for Davis Station[1]	**12.1**		**12.3**		**10.4**	

1 Barker, S.F., Packer, M., Scales, P.S., Gray, S., Snape, I., Hamilton, A.J. (2013) Pathogen reduction requirements for direct potable reuse in Antarctica: Evaluating human health risks in small communities. Science of the Total Environment, 461-462 (2013) 723-733

Helminths were not included in the LRV Table and were not investigated as part of the QMRA study of water recycling at Davis Station[1]. This is because there was insufficient data on which to base a QMRA study. This lack of data is exemplified in various guidelines related to water recycling. Page 2 of the Victorian Validation Guidelines[2] state "The guidelines focus on managing the acute health risks posed by pathogens in recycled water, and therefore only address the validation of treatment processes to meet microbial water quality objectives. Algal toxins and chemicals, as well as helminth reduction, are not addressed." Also, the Australian Guidelines for Water Recycling (AGWR)[3] state on page 40 that *Cryptosporidium* should be used as a reference pathogen for protozoa and helminths. It also states that "helminth reduction is most relevant to agricultural irrigation schemes that are typically of a lower quality than Class A and so outside the intended scope of these guidelines. In general the Chief Veterinary Officer within the Department of Primary Industries should be consulted in relation to helminth risks."

An estimate of the helminth LRV required for Davis Station could be made based on the ratio increase between large scale municipal water recycling LRV and the calculated LRV for Davis for protozoa, and this would be consistent with using *Cryptosporidium* as a reference pathogen. This ratio was 1.3 and applying this factor would increase the required helminth removal from 8 for large scale municipal wastewater treatment systems to 10.4 LRV. If *Cryptosporidium* is used as the reference for helminths, then a credible removal of 12 LRV could be achieved across the system.

Helminths are larger than protozoa (generally 20-30 microns in size compared to 3 microns for *Cryptosporidium*) and are resistant to oxidative attack. The larger size of helminths allows their removal in membrane systems, which rely on size exclusion, to be conservatively estimated by *Cryptosporidium* LRV. Jimenez-Cisneros and Maya-Rendon[4] suggest 4 LRV helminths for MBR but this is only based on theoretical consideration. Branch et al.[5] used operating MBR data to identify 4 LRV for protozoa (and hence for helminths) at the 95% confidence limit. Combined with a LRV 4 across the ceramic membrane and a likely LRV of 4 across the RO, this provides a credible removal of 12 LRV.

Cryptosporidium are effectively inactivated by UV disinfection enabling a LRV of 4 to be claimed. However, helminths are more resistive to inactivation by UV than *Cryptosporidium*. Brownell and Nelson[6] investigated inactivation of *Ascaris suum* as a function of UV fluence and identified that a dose of 400 mJ/cm^2 (4,000 J/m^2) was required for 2 LRV. UV dose in the Davis AWTP usually exceed 400 mJ/cm^2, so a

2 Department of Health, Victoria, Guidelines for validating treatment processes for pathogen reduction, Supporting Class A recycled water schemes in Victoria, Feb. 2013

3 Australian Guidelines for Water Recycling: managing health and environmental risks (Phase 2) Augmentation of Drinking Water Supplies 2008 Evinronment Protection and Heritage Council, National Health and Medical Research Council, Natural Resource Management Ministerial Council, http://www.environment.gov.au/water/quality/publications/nwqms-australian-guidelines-water-recycling-managing-health-phase2)

4 Jimenez-Cisneros, B.E., Maya-Rendon, C. Helminths and Sanitation, Communicating Current Research and Educational Topics and Trends in Applied Microbiology, A. Méndez (Ed), Formatex, http://www.formatex.org/microbio/pdf/Pages60-71.pdf (Accessed 26 June 2015)

5 Branch, A., Trinh T., Zhou, B., Leslie, G., Le-Clech, P., Chemical cleaning in membrane bioreactors: implications for accreditation in water recycling. OzWater15, AWA, May, 2015, paper 131

6 Brownell, S.A., Nelson, K.L. (2006) Inactivation of singled cell *Ascaris suum* Eggs by low pressure UV radiation. Applied and Environmental microbiology, 72(3), 2178-2184

LRV 2 for UV is also likely further increasing the likely LRV for the system.

Therefore, effective removal of helminth across the Davis AWTP is managed by use of *Cryptosporidium* as a reference pathogen.

Membrane Bioreactor (MBR)

MBR Design and Specifications

Supplier - Martin Membrane Systems
Membrane type – flat sheet, 150,000 MWCO polyether sulfone (PES) ultrafiltration membrane on a non-woven polypropylene support (nominal pores size is 35 nm and the maximum pore size is 0.1 μm)
pH range – 2.0 – 10.0
CIP pH – 1.5 – 11.5
Max. TMP – 0.6 bar
Intensive Cleaning – 1,500 ppm free chlorine, pH 10.5 or 4,000 ppm H_2O_2, pH 3-7 all at ≤25˚C
Maintenance cleaning - 500 ppm free chlorine, pH 10.5 or 2,000 ppm H_2O_2, pH 3-7 all at ≤25˚C
No backwashing but has continuous air scouring and relaxation periods
Flux – 17 L/m^2.h (75 m^2 membrane area for 1200 L/hr flow)
Monitoring on filtrate - pH, conductivity, ammonia, nitrate and phosphate.

Removal Mechanisms

For protozoa, helminths and bacteria, the pore size of the membrane is usually less than the size of the pathogens, so removal is via size exclusion as well as predation. Virus is removed by predation, the fouling layer and adsorption. For the membrane used by AAD, the pore size is small (nominal 35 nm) which is similar in size or smaller than many virus.

Reported LRV for MBRs

Branch, Leslie and Le-Clech[7]: Literature review of published LRV for MBRs (33 papers). – 5th percentile LRV for MS2 > 2 and for somatic and Qβ > 3, for *Ecoli* (bacterial indicator) >4.

Turbidity can be used to detect breaches of the membrane.

Required Operating Parameters

Helminths, protozoa and bacteria will be removed via size exclusion because of their size relative to the pore size of the membrane, while removal of virus will be dependent upon adsorption on biomass and the membrane, and predation. Therefore, virus removal is more susceptible to operating conditions, and the operating window for MBR operations will be determined by virus removal.

There is very little data available on pathogen removal from MBRs as a function of the operating characteristics. The AWRCoE NatVal project is investigating this, but at the time of writing there were no critical operating conditions that had been identified. What had been identified was that LRVs decreased immediately after membrane cleaning, and that virus rejection increased with fouling of the membrane.

7. Amos Branch, Greg Leslie, Pierre Le-Clech, AWA Ozwater14, 29th April – 1 May, 2014, Brisbane, paper 98

Hence, the required operating conditions for the MBR to maintain an LRV of 2 were chosen to reflect what would be considered normal operating conditions, as under these circumstances >2 LRV virus and >4 LRV bacteria were found for the 5th percentile by Branch et al.[1]. Also in NatVal 2.2 sub Project 1 – MBR Deliverable 1 report, page 48, there are MBR CCPs listed for 4 operating sites. These CCPs include values for temperature, filtered turbidity, TMP and flux.

Therefore the following operating conditions are set for the MBR to be credited with 2 LRV.

pH between 6 – 8 (outside of this range would indicate the biological process is not operating in a typical manner)

temperature > 13˚C (listed as a CCP for 1 operating site listed in the NatVal report and affects the biological process and the TMP for the MBR)

Flux = <32 LMH (listed as a CCP for 1 operating site listed in the NatVal report; high flux may lower LRV from size exclusion)

TMP ≤ 85 kPa (listed as a CCP for 1 operating site listed in the NatVal report; high TMP indicates fouling which would increase the LRV but greater than 85 kPa does indicate unusual operating conditions)

Turbidity ≤0.2 NTU (ie. not >0.2 NTU for more than 10 minutes (2 consecutive readings).

Design parameters for the MBR

Summer: MLSS = 14,000 mg/L and SRT = 15 days

Winter: MLSS = 5,000 mg/L and SRT = 25 days

The plant will have a MLSS sensor to control the MLSS

Ozone

Ozone design and specifications

Supplier – Wedeco, OCS-GSO 10; Maximum ozone production = 30 g/h; continuous with internal recycle; HRT_{10} = HRT when 10% of the flow has exited the ozone system (flowrate = 20 L/min) = 4.8 min (4.8 and 5.2 min measured for HRT_{10} using Rhodamine WT).

Removal Mechanisms

Pathogens are inactivated by oxidation with ozone.

Reported LRV for Ozone

US EPA Long Term 2 Enhanced surface water treatment rule toolbox guidance manual[8], April 2010 (http://www.epa.gov/safewater) Chapter 11, Table 11.1 outlines the required CT values for *Cryptosporidium* inactivation from surface waters and these values were determined using reagent grade water. The required CT value = 2.0 at 20˚C for a *Cryptosporidium* LRV of 0.5. For virus, the US EPA Guidance Manual Disinfection Profiling and Benchmarking[9], Appendix C outlines the CT values for inactivation of virus by ozone from surface waters. The CT value = 0.5 for a virus LRV of 4 at 20˚C, and 0.25 for a virus LRV of 2 at 20˚C. These CT values will be applicable for particle free water, as will be experienced at Davis Station, where MBR filtrate is fed to the ozone unit.

At Selfs Point, however, the feedwater turbidity varies between 1-3 NTU and is commonly at 1.3 NTU. Particles in wastewater have been previously shown to require higher ozone CT values[10] for feedwater turbidity vales between 1-5 NTU. Work by Melbourne Water[11] has shown that ozone CT values required for *Cryptosporidium* inactivation in biological media filtration (BMF) filtrate with turbidity between 0.5-2 NTU was similar to those determined in reagent grade water[2]. The BMF water in the Melbourne Water work was pre-ozonated before the BMF, and the pre-ozonation process showed variable inactivation of pathogens. Hence, the CT values used are applicable for Davis Station where MBR effluent will be particle free but less confidence in these values exists for ozonation of Self's Point effluent.

To validate the ozone system at Selfs Point according to the Draft Ozone Validation Guidelines was problematic because of the non-particle free nature of this water and the resources required to validate the process according to these guidelines. Given the Selfs Point feed water to the ozone system is of significantly poorer quality than the expected MBR feed at Davis Station, the LRVs conservatively claimed for Davis will be those that can be demonstrated

8. US EPA Long term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual, April 2010 http://www.epa.gov/safewater/disinfection/lt2/pdfs/guide_lt2_toolboxguidancemanual.pdf
9. US EPA Guidance Manual Disinfection Profiling and Benchmarking, August 1999, http://www.epa.gov/ogwdw000/mdbp/pdf/profile/benchpt1.pdf
10. US EPA Effect of particulates on ozone disinfection of bacteria and virus in water, August 1979
11 Mieog and McNeil, Recycled water treatment on a large scale using multiple disinfection barriers at Melbourne Water's Eastern Treatment Plant. AWA Water Recycling conference, Brisbane, 2-3 July, 2013

by operation of the plant at Selfs Point. Currently, all monitoring of the ozone system at Selfs Point has demonstrated >2 LRV for native *E. coli* when either there were no *E. coli* left in the treated water or the feedwater concentration was characterised as being >2,419 MPN/100 mL, and > 2.7 LRV when a LRV could be calculated (see Table 2 and Figure 1). This has been true even when the feedwater deteriorated badly (turbidity >5 NTU, ammonia >6 mg/L) during a scheduled settler maintenance period. LRV of >4 for *E. coli* has been reported for periods of low ozone residual. LRV >2 for virus has also been observed at Selfs Point even when there was no residual ozone (Table 2). Operation at Davis Station will target ozone residuals equivalent to those required for 4 LRV virus by the USA EPA CT values, but in the event these cannot be reached, the ozone dose will remain high (11.7-14 mg/L and 1.3-1.7 mg O_3/ mg DOC). This is the mode of operation at Selfs Point that has been demonstrated to achieve LRV >2.

Monitoring data from Selfs Point, up to the 27/5/15, are shown in Table 2.

Table 2: Microbial concentrations and LRV for ozonation.

Date	*E.coli*			Somatic Coliphage			Residual Ozone (mg/L)
	Feed (MPN/100 mL)	Post ozone (MPN/100 mL)	LRV	Feed (pfu/100 mL)	Post ozone (pfu/100mL)	LRV	
17/9/14	1986.3	3.1	2.81				0.47
24/9/14	1553.1	4.1	2.58				0.21
1/10/14	1732.9	5.2	2.52				0.39
8/10/14	1553.1	4.1	2.58				0.48
15/10/14	>2419.6	2.0	3.08				0.30
22/10/14	>2419.6	4.1	>2.77				0.16
29/10/14	>2419.6	1.0	>3.38				0.87
5/11/14	>2419.6	3.1	>2.89				0.23
12/11/14	>2419.6	4.1	>2.77				0.28
19/11/14	>2419.6	1.0	>3.38				0.04
26/11/14*	13500	1.0	4.13				0.00
2/12/14	24300	2.0	4.08				0.01
10/12/14	290900	4.1	4.85				0.04
17/12/14	285100	39.9	3.85	834	<1	>2.92	0.00
21/1/15	770100	24.3	4.50				0.00
28/1/15	90900	12.2	3.87				0.02
28/1/15	53300	7.5	3.85				0.00
4/2/15	62000	9.7	3.81				0.00
4/2/15	18700	12	3.19				0.01
11/2/15	>2419.6	21.6	>2.05				0.00
11/2/15	>2419.6	12.1	>2.30				0.00
18/2/15	150000	72.3	3.31				0.00
18/2/15	108100	37.9	3.46				0.00
25/2/15	25300	3	3.93	3000	1	3.48	0.00
25/2/15	27500	15.8	3.24				0.03
4/3/15	28200	6.3	3.65				0.00
4/3/15	28100	55.4	2.71				0.00
11/3/15	74300	24.6	3.48				0.00
11/3/15	70600	14.6	3.68				0.00
25/03/15	39300	2	4.29	12000	7	3.23	0.14
25/03/15	48700	10.8	3.65				0.12
1/04/15	8600	4.1	3.32				0.00
1/04/15	9700	18.9	2.71				0.10
15/04/15	14800	2	3.87				0.10
15/04/15	5200	1	3.72				0.05
22/04/15	3100	7.5	2.62	4200	5	2.92	0.16
22/04/15	5200	1	3.72				0.05
29/04/15	9700	7.3	3.12				0.19
29/04/15	7500	8.7	2.94				0.15
6/05/15	16100	3	3.73	2500	<1	>3.40	0.46
6/05/15	14600	3.1	3.67				0.63
20/05/15	128650	27.5	3.67				0.10
20/05/15	133300	23.3	3.76				0.42
27/05/15	178500	7.4	4.38				0.36
27/05/15	222400	5.2	4.63				0.39

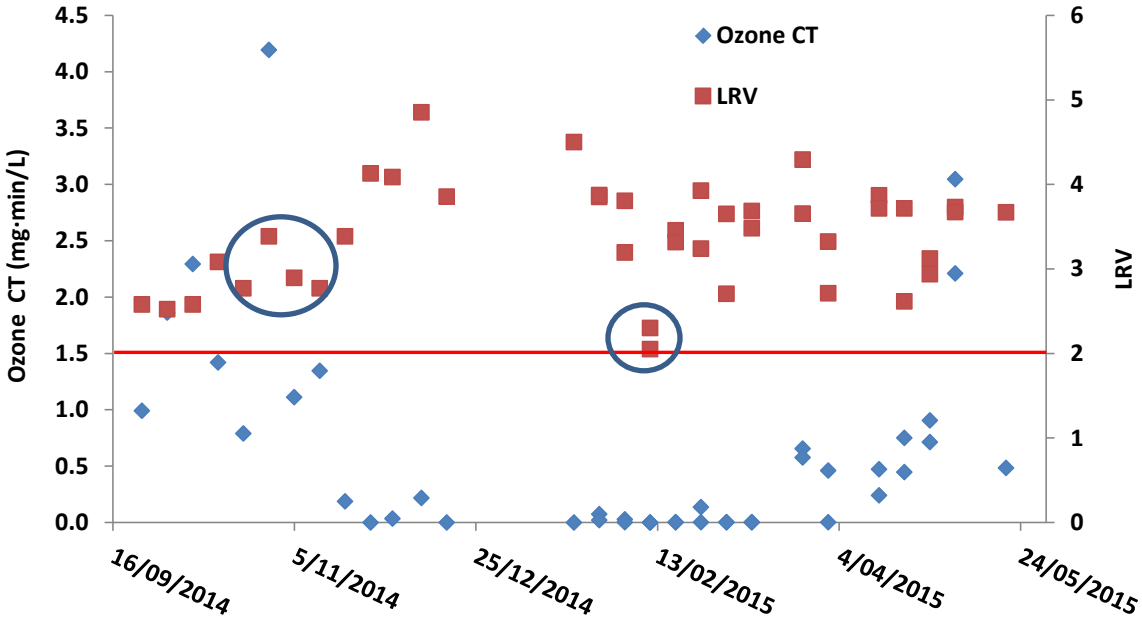

Figure 1: LRV and ozone CT over time. Blue circles identify > LRV where the feed concentrations were >2419.6 MPN/100 ml.

Note: For this system, the US EPA CT values (@19˚C) require a residual of 0.35 mg/L ozone for 0.5 LRV protozoa, 0.1 mg/L for 4 LRV virus and bacteria and 0.05 mg/L for 2 LRV virus and bacteria.

Required Operating Parameters

Flowrate < 20±10% L/min (T_{10} = 4.8 min)

Residual concentration >0.05 for LRV =2 (virus) (claimed LRV)

Or

Flowrate < 20±10% L/min (T_{10} = 4.8 min)

ozone dose > 11.7 mg/L and >1.3 mg O_3/ mg DOC

Ceramic Microfiltration (CMF)

CMF design and specifications

Supplier - METAWATER
Membrane type – ceramic aluminium oxide with surface coating, nominal pore size of 0.1 μm
System Design TMPmax = 1.4 bar (METAWATER *TMP max.* = 6 bar (during backwashing))
Flux – 48 L/m^2.h
On-line monitoring – turbidity measurement of the filtrate

Removal Mechanisms

For protozoa, helminths and bacteria, the pore size of the membrane is usually less than the size of the pathogens, so removal is via size exclusion. Virus are removed by adsorption and the fouling layer.

Reported LRV for ceramic MF

METAWATER has had their membrane certified by the Department of Health Services, State of California, USA for 4 LRV for *Cryptosporidium* and *Giardia*, and 1 LRV for virus in the absence and presence of coagulant using a surface water feed. This certification is valid for temperatures between 0 – 30˚C (32 - 86˚F), for a pressure decay test conducted at 20 psi (138 kPa) with a pressure decay rate <0.20 psi/min (1.38 kPa/min).

Dow, Murphy, Clement and Duke[12] experimentally determined LRV on Eastern Treatment plant water using METAWATER ceramic MF (limited number of samples taken – not a true validation): LRV for MS2 > 4 (flux 200 L/m^2.h in clean water) and for *E. coli* (bacterial indicator) LRV >2.3 (zero counts in permeate, flux = 150 L/m^2.h in clean water). Therefore, the certification of 1 LRV for virus by the Department of Health Services, State of California, USA is conservative.

Therefore, LRV=4 is claimed for protozoa and helminths, and LRV=1 for bacteria and virus is also claimed.

Required /operating Parameters based on the Department of Health Services, State of California, USA certification:

Temperatures = 0 – 30˚C (32 - 86˚F)

Operating flux ≤ 298 L.m^{-2}.hr^{-1} (175 gfd) at 20˚C

Pressure hold test is conducted at ≥ 138 kPa (20 psi)

Pressure decay rate <1.38 kPa/min (0.20 psi/min)

Between PDT tests turbidity is monitored on-line and the turbidity is required to be <0.3 NTU. The value of 0.3 NTU was obtained from operating data from trials at Selfs Point Wastewater Treatment Plant.

12. Dow, N., Murphy, D., Clement, J., & Duke, M. (2013). Outcomes of the Australian Ozone/Ceramic Membrane Trial on Secondary Effluent. AWA Water, 40(6), 45-51

Biologically Activated Carbon (BAC)

BAC design and specifications

EBCT – 20 minutes
Volume = 400 L
Backwash - air scour and backwash; activated by filtrate volume or excessive pressure drop or turbidity in the filtrate
Carbon - Acticarb BAC GA1000N 8x30 Mesh
Performance measurements – On-line turbidity measurements (usually 0.15 - 0.28 NTU); Performance target is <0.2 NTU

No LRV claimed over the BAC.

Reverse Osmosis (RO)

RO Design and Specifications –

Membranes- Dow BW30
Module design – 5 x single elements in series
Mode of operation – operated at 70% recovery with recirculation to achieve this, semi-continuous with near continuous operation in the summer and operation for 4 hours every second day during winter, membranes are flushed with permeate whenever they shut down. An osmotic backwash has been observed when shut down.
Average Flux – 23 $L/m^2.h$
Monitoring permeate - conductivity, flowrate
On-line integrity sensors – conductivity across each element and across the feed and permeate, pressure decay test for protozoa and helminths.

Removal Mechanisms

Size exclusion for all pathogens.

Reported LRV for RO

It is generally understood that RO can achieve very high LRVs for all pathogens but may be compromised by faulty o-rings or defects in the membrane[13]. Therefore, on-line monitoring is required and the limitations of the on-line verification usually limit the approved LRV values, with LRV of 1.5-2 being usual.

This system uses conductivity across the process for on-line verification, as well as a pressure decay test (PDT) designed to detect a 3 μm defect to confirm RO integrity for rejection of protozoa and helminths. The PDT has been shown in laboratory testing to achieve a LRV of >2 for particles >3 μm (protozoa and helminths) at a test pressure of only 45 kPa. Operating data for conductivity across the RO elements has consistently demonstrated an LRV of >2 for protozoa and helminths based on the PDT (see Figure 2) and >97% conductivity rejection and thereby an LRV of >1.5 for virus and bacteria (see Figure 3).

LRV of 1.5 can be claimed for pathogens based on conductivity across the RO system, and a LRV of 2 can also be claimed for protozoa and helminths based on the PDT.

13. Department of Health, Victoria, Guidelines for validating treatment processes for pathogen reduction, Supporting Class A recycled water schemes in Victoria, Feb. 2013

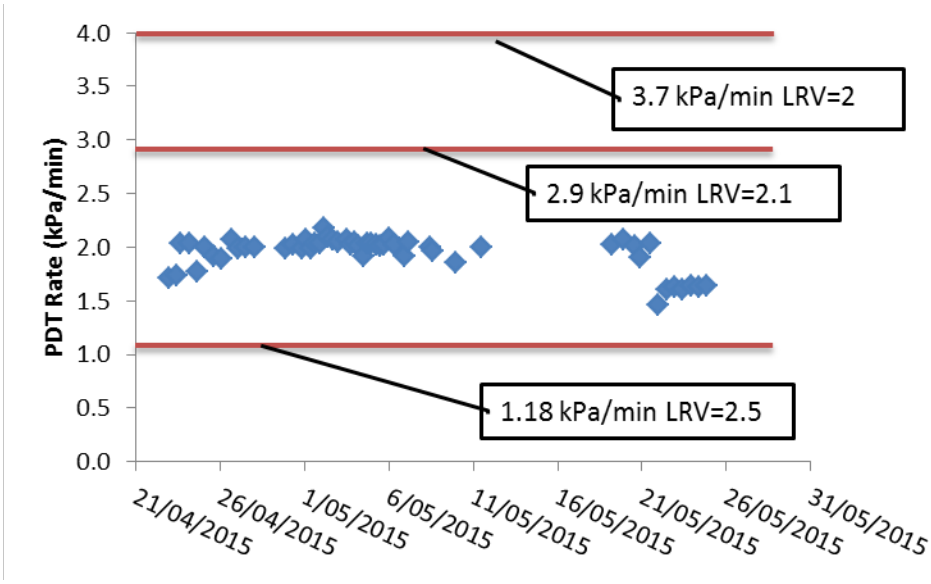

Figure 2: Typical pressure decay rates for the RO system (required pressure decay rate <3.7 kPa/min) for Selfs Point operation.

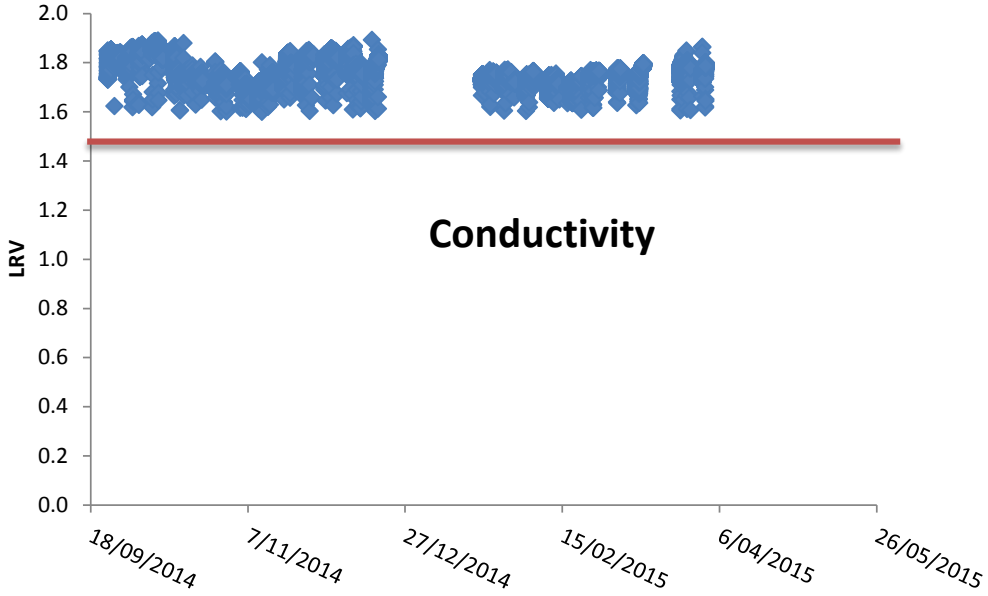

Figure 3: Typical LRVs calculated from conductivity measurements of the feed and permeate at Selfs Point.

Required Operating Parameters

Conductivity is a conservative surrogate for pathogen removal across reverse osmosis membranes, as the conductivity reduction is always lower than the pathogen reduction. Hence, operating parameters have no effect on the use of conductivity for LRV calculations, and there is no requirement to control the operating parameters of the RO system to a region where LRV measured by conductivity is valid. Data confirming this is contained in the AWRCoE NatVal

project on RO validation and in the WateReuse Research Foundation project (WateReuse–12–07).

The pressure decay test (PDT) is used to identify membrane breaches of >3 µm under pressure decay conditions. Since maximum back pressure of the RO system in the pilot plant is 40 kPa and contact angle of BW30 membrane is 62º, the pressure to achieve a resolution of 3 µm based on Equation (3) is 85 kPa (45 kPa for test TMP and 40 kPa for backpressure). Using equations 1, 2 and 3 shown below from the US EPA guidance manual[8], the measured pressure decay rate on the demonstration plant should be <3.7 kPa/min when operated within the following process conditions.

Temp =15 - 25°C

Specific flowrate >1.09 $L.min^{-1}.bar^{-1}$

Overall RO system recovery >60%

Pressure decay rate test pressure = 85 kPa, Pressure decay rate <3.7 kPa/min

Equations for determining the LRV from an RO pressure decay test based on the USA EPA Guidelines[14]:

$$LRV_{DIT} = \log\left(\frac{Q_p \cdot ALCR \cdot P_{atm}}{\Delta P_{test} \cdot V_{sys} \cdot VCF}\right) \quad (1)$$

$$ALCR = 170 \cdot Y \cdot \sqrt{\frac{(P_{test} - P_b)(P_{test} + P_{atm})}{(492 + 1.8T) \cdot TMP}} \quad (2)$$

$$d = \frac{P_{test} - P_{b,max}}{k\pi\sigma \cos\theta} \quad (3)$$

where Q_p is the permeate flowrate, *ALCR* is air-liquid conversion ratio, P_{atm} is the atmospheric pressure, ΔP_{test} is the pressure decay rate, P_{test} is the pressure decay testing pressure, V_{sys} is the volume of the pressurised vessel, P_b is the back pressure on the permeate side, *VCF* is the Volumetric Concentration Factor, *Y=Recovery/(1-Rcovery)* here is the net expansion factor for compressible flow, *TMP* is the operation trans-membrane pressure, d is the size of the defect, k is the geometric factor of the defect, θ is the contact angle of the membrane, and σ is the surface tension between the air and liquid.

14 US EPA Membrane Filtration Guidance Manual, Nov, 2005, http://www.epa.gov/ogwdw/disinfection/lt2/pdfs/guide_lt2_membranefiltration_final.pdf

Ultraviolet (UV) Disinfection

UV Design and Specifications

UV system- Wedeco Specktron 6, low pressure lamps
Maximum Intensity – 92 W/m^2
Lamp life – See graph below
UV units in series – 2 specktron UV units operated in series, with a 3rd system as backup (ie. non-operational unless one lamp fails). The two lamps in series allow the CCP to be met even if one lamp fails.
Monitoring of UV dose – The intensity of UV radiation at the edge of the UV unit is measured by an intensity sensor.
Certification – Certified to DVGW standard.

Ageing of lamps occurs as shown in Figure 4. The output stabilises at 80% of the as new UV intensity after approximately 6000 hours of operation, and this should be accounted for in the design of the system. The Specktron 6 has a UV intensity sensor built into the system which will continuously monitor UV intensity.

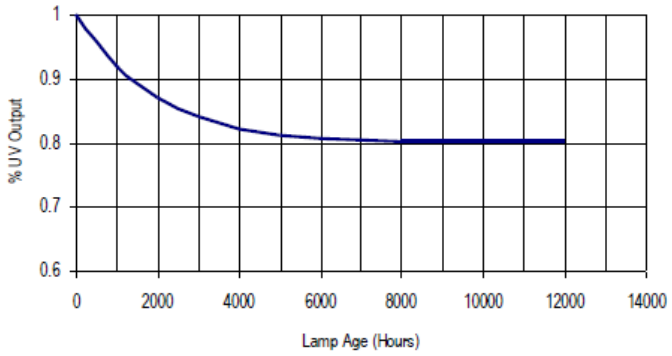

Figure 4: Ageing of UV lamps.

UV Inactivation Mechanisms

UV damage of DNA

Reported LRV for UV

A UV dose of 186 mJ/cm^2 is required to achieve 4 LRV for virus[15]. The Water Corporation water recycling plant has been credited with 4 LRV for virus, bacteria and protozoa based on a dose of 200 mJ/cm^2 for 4 DVGW accredited UV reactors in series each dosing at least 50 mJ/cm^2.

For the AAD process, a UV dose of >186 mJ/cm^2 for each of the two reactors in series can be verified by the UV intensity sensor and the flowrate through the UV system. The hydraulic residence time (HRT) distribution through a UV unit has been measured and plug flow was approximated. The HRT_{10} (10% of flow has passed through the reactor) was 1.07 min at a flowrate of 14.4 L/min (design flowrate = 14 L/min, 70% recovery) and 1.25 min at 12 L/min.

15. USEPA Ultraviolet disinfection guidance manual for the final long term 2 enhanced surface water treatment rule, EPA 815-R-06-007, (2006)

Operating doses for the AAD plant commissioned at Selfs Point is shown in Figure 5 (flowrate approx 14 L/min). The minimum dose per lamp is >300 mJ/cm^2, which is more than 1.5 times the required 186 mJ/cm^2 for 4 LRV virus. Therefore, 4 LRV for virus, bacteria and protozoa is claimed.

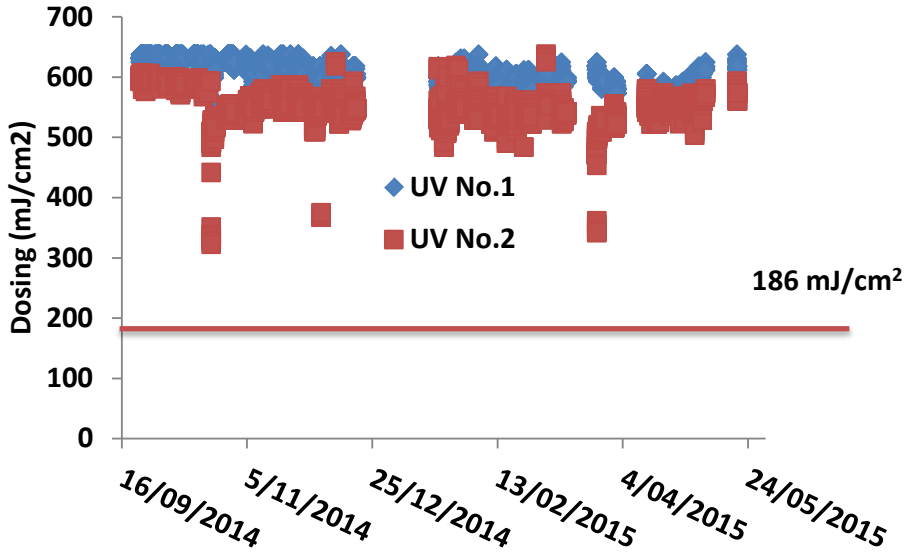

Figure 5: Operating data for UV doses for the 2 UV lamps in series.

Required Operating Parameters

A minimum UV dose of 186 mJ/cm^2 is required for 4 LRV virus.

UV dose = Measured Intensity (I) x selectivity x accuracy x residence time$_{10}$ (T_{10})

Intensity is measured on-line using the UV sensor at the wall of the UV unit.

The selectivity of the UV lamp for production of UV_{254} is 99%.
The accuracy of the sensor is ±3% (minimum accuracy = 97%).
T_{10} = minimum residence time for 10% of the flow = Volume of the UV unit x flowrate x coefficient. Volume of the UV unit is 19 L. The flowrate is set at ≤14 L/min. The minimum coefficient for this flowrate (±10%) is 0.79 (measured by tracer studies). Therefore T_{10} = 1.07 min = 67sec.

The dose is calculated using the on-line intensity measurements: Dose = Intensity x 0.99 x 0.97 x 67 sec ≥ 186 mJ/cm^2.
Therefore, the Intensity ≥ 28.9 W/m^2.

Hence, required operating parameters are:

Flowrate ≤14 L/min ±10%
UVT ≥ 90%/cm (measured weekly offline)

Calcite Contactor

Calcite Contactor Design and Specifications

EBCT - 4.1 min
Design pH – 6.5 - 8.0
Monitoring – pH of permeate
Design flowrate = 20 L/min (maximum flowrate)

No LRV claimed for the calcite contactor.

Chlorination

Chlorination Design and Specifications

Contactors - 2 x 1,000 L contactors; 1 contactor holds a batch of water to reached the desired CT while the other is filling; allows continuous filling of the contactors.
LRV claimed – 4 for bacteria and virus
Required CT – >22 mg.min/L for pH < 8.5, temp ≥10˚C, turbidity <2.0 NTU[16]
On-line Monitoring – pH into contactor (after calcite contactor), chlorine concentration into contactor after dosing and chlorine concentration in a side stream recirculation loop of the tank and in the discharge from the tank.

Removal Mechanisms

Oxidation of pathogens.

Reported LRV for Chlorination

LRV of 4 can be achieved for bacteria and virus, with virus requiring the larger CT value. The Department of Health, Victoria, Guidelines for validating treatment processes for pathogen reduction was used to specify the required CT value for 4 LRV virus of >22 mg.min/L (pH<8.5, temp ≥10˚C, turbidity <2.0 NTU).

Required Operating Parameters

The CT values for the chlorination system were taken from the Department of Health, Victoria, Guidelines[9] for the feedwater to the chlorination system having:

pH≤8.5

Temp ≥10˚C, and

Turbidity <2 NTU.

The pH is measured on-line between the calcite contactor and the chlorination system. Temperature is measured after the calcite filter. Turbidity is measured after the BAC to be <1 NTU, and this water passes through RO with a conductivity based LRV of >1.5 and a PDT of greater than 2 LRV. These two tests require the RO system to have no breaches (no beach of membrane material based on conductivity and no o-ring, membrane or glue line leaks based on PDT), so the turbidity post RO will be less than that measured on the BAC.

The biggest risk is the pH >8.5 as the pH reading is only accurate to ±0.5 pH units and addition of sodium hypochlorite may add alkali to the water, particularly if the concentration of sodium hypochlorite has degraded. Therefore, the pH criteria for feed to chlorination is set at pH <8 but the CT value assumes pH<8.5. This corresponds to a CT ≥22 mg.min/L (LRV = 4 for pH≤8.5, temp >10˚C, and Turbidity <2 NTU)[9] to ensure appropriate disinfection.

16 Department of Health, Victoria, Guidelines for validating treatment processes for pathogen reduction, Supporting Class A recycled water schemes in Victoria, Feb. 2013

Appendix A: Hydraulic retention time measurements

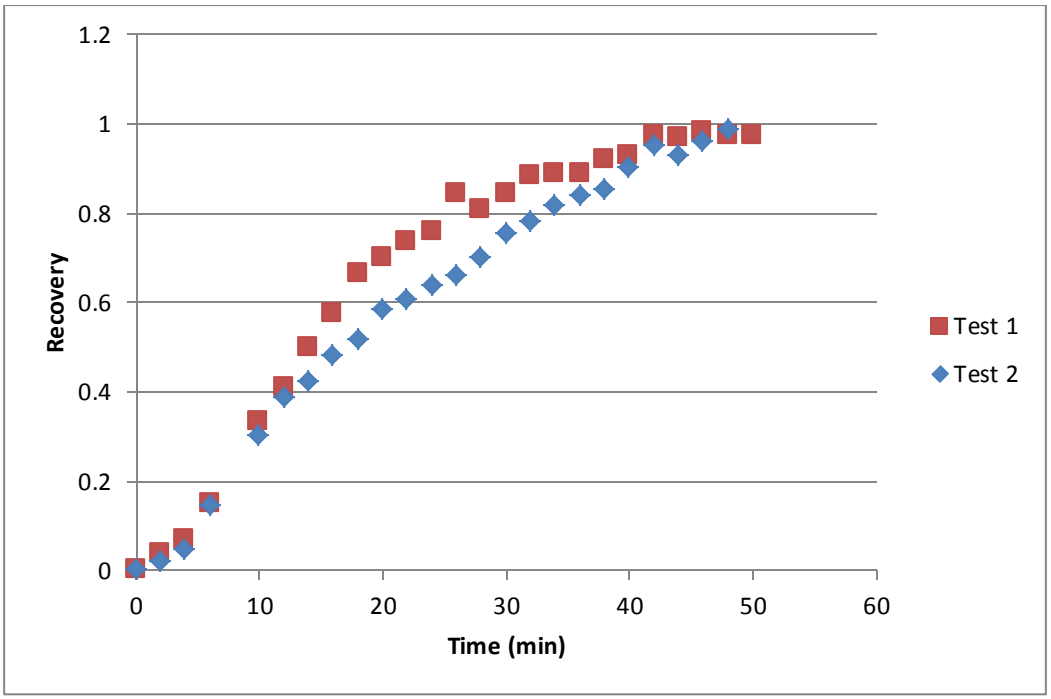

Figure 6: Ozone system: Rhodamine WT HRT Test Data (flowrate = 20 L/min; Design flowrate).

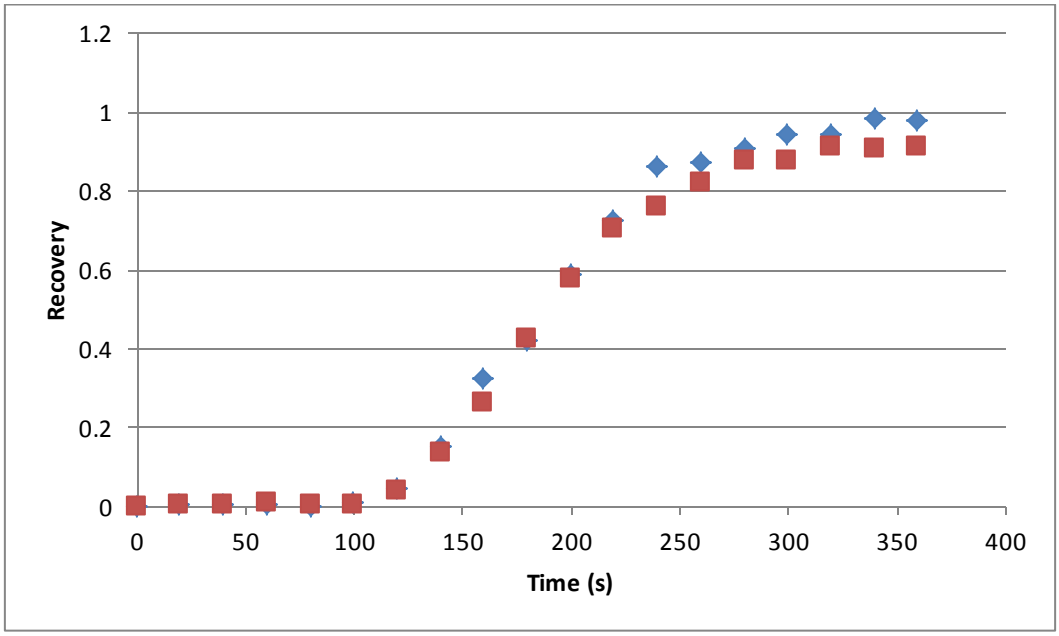

Figure 7: UV Hydraulic Retention Time Tests: Rhodamine WT, Flowrate = 14 L/min (design flowrate) – Tests 1and 2.

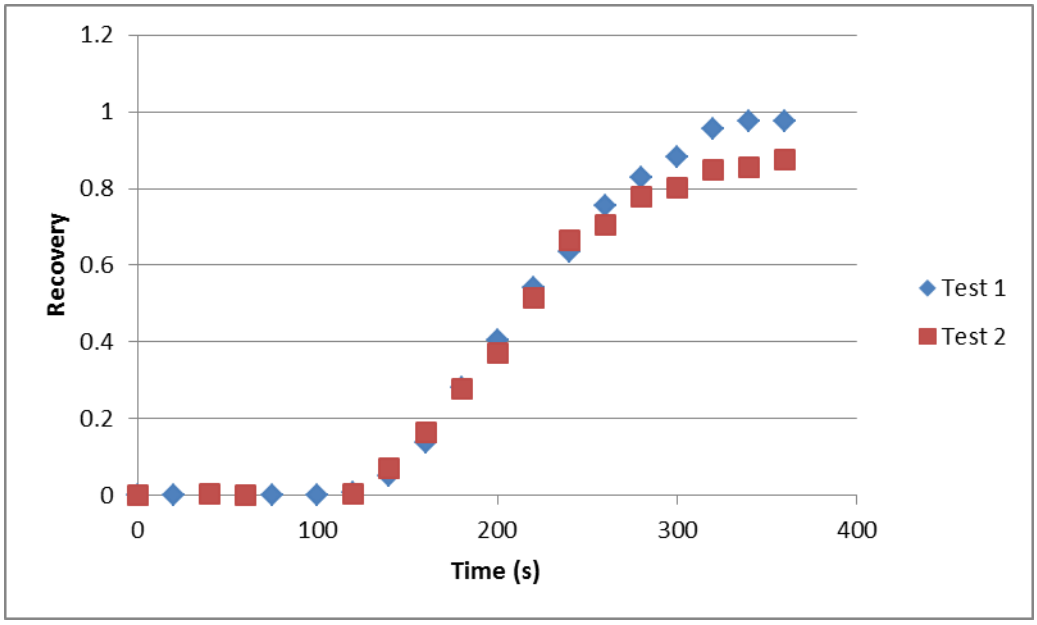

Figure 8: UV Hydraulic Retention Time Tests: Rhodamine WT, Flowrate = 12 L/min (design flowrate) – Tests 1and 2.