UV Disinfection for Class A Water Recycling

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ABSTRACT

In December 2004, Melbourne Water commissioned and obtained Class A accreditation from the Victorian EPA and Department of Human Services (DHS) for a 60 million litres per day (MLD) state-of-the-art chlorine and UV disinfection plant at Western Treatment Plant, Werribee, Victoria. From January 2005, Class A recycled water has been supplied to the nearby Werribee Irrigation District (WID) for the production of vegetables, mainly lettuces, cauliflowers and broccoli, which can be cooked or eaten raw.

KEYWORDS

UV disinfection credits, MS2 bacteriophage, UV validation, Class A recycled water, *Cryptosporidium* and *Giardia* inactivation.

BACKGROUND

Ultraviolet (UV) light disinfection technology is used increasingly around the world to disinfect drinking water and recycled water. Although the application of the germicidal properties of UV light was pioneered in the early 1900s, it was not until the 1990's that major technological advances in equipment design, increased understanding of the process fundamentals, development of reliable validation and performance monitoring methods, as well as the growing need to address the often conflicting call for improved microbial water quality without forming additional disinfection by-products (DBPs) lead to the rapid adoption of UV disinfection for recycled water and drinking water that continues to this day (Whitby et al. 2004).

Pathogens such as *Cryptosporidium* are highly resistant to commonly used chlorine-based disinfectants, but UV light has been proven to be one of the most effective means for inactivating these microbes. Amazingly, scientific evidence proving the effectiveness of UV light against *Cryptosporidium* was not fully established until the late-1990s. UV Doses as low as 3 mJ/cm^2 are effective in achieving more than 3-log reductions for *Cryptosporidium* in drinking water.

The application of UV disinfection in the USA has been largely driven by the development of the United States Environmental Protection Agency's (USEPA) Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) to further control microbial contamination of drinking water, in particular *Cryptosporidium and Giardia*, without forming additional DBPs (Hulsey et al 2004). The design, operation and maintenance needs of ultraviolet disinfection systems differ greatly from those for traditional chemical disinfectants such as chlorine. To provide a framework for the application of UV disinfection technology, the USEPA released (June 2003) a draft *Ultraviolet Disinfection Guidance Manual* (UVDGM).[1] This draft UVGM was adopted by Melbourne Water and Department of Human Services to apply UV disinfection for Class A recycled water production for the WID recycled water project.

INTRODUCTION

Since December 2005, up to 55 MLD of recycled water (up to 8,500 ML per year) has been delivered from Melbourne Water's Western Treatment Plant at Werribee to the water retailer, Southern Rural Water, for distribution to more than one hundred vegetable growers in the Werribee Irrigation District. This has increased their security of supply and contributes significantly to the Government's *Our Water Our Future* action plan. Since the water is used for production of vegetables, mainly lettuces, cauliflowers and

broccoli, which can be cooked or eaten raw, it must be produced by treatment processes capable of providing a 7-log reduction in viruses and 6-log reduction in protozoan parasites and is termed, in Victoria, Class A water.

Table 1. ***Western Treatment Plant, Class A Recycled Water Production Volumes (millions of litres)***

Year	July-September	October-December	January-March	April-June	TOTAL
2004/05	-	19	183	155	357
2005/06	101	652	568	33	1,354

By 2008/09, Class A recycled water will also be supplied to the metropolitan water retailer City West Water for use in residential dual pipe systems for toilet flushing, garden and open space watering, commercial and industry use, thereby saving drinking water for future generations. Usage of recycled water in the nearby Werribee Tourist Precinct, a significant tourist destination, will also be increased with the aim of further reducing stress on the Werribee River.

As Victoria's first Class A recycled water scheme, the Werribee Irrigation District (WID) recycled water scheme has demonstrated the application of recycled water as a reliable and sustainable water resource for food production. The scheme has brought an immediate and substantial contribution to the Victorian Government's water recycling target of 20 per cent by 2010; it will also reduce the input of nitrogen to Port Phillip Bay by some 70 tonnes a year and will reduce stress on the Werribee River and underground aquifers.

Figure 1 shows the locality of the Class A disinfection plant at Melbourne Water's Western Treatment Plant.

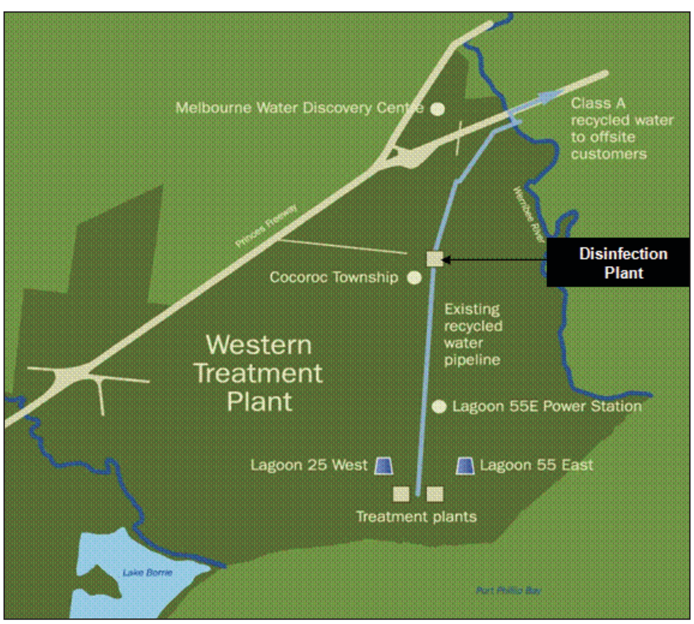

Figure 1. ***WTP Class A Disinfection Plant locality plan.***

[1] The Final UVDGM was issued in November, 2006 – see http://www.epa.gov/safewater/disinfection/lt2/pdfs/guide_lt2_uvguidance.pdf

Figure 2 shows process train for the Class A Disinfection Plant at Western Treatment Plant.

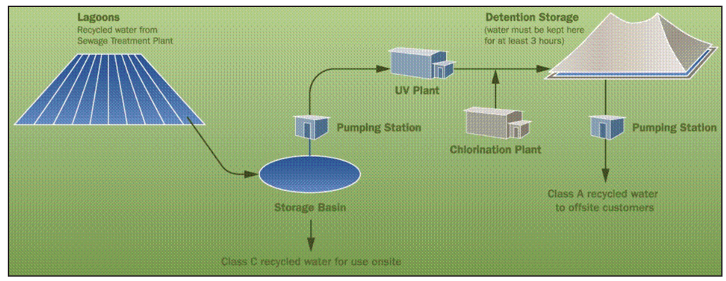

Figure 2. ***Class A recycled water process treatment plan at Melbourne Water's Western Treatment Plant***

TIMETABLE

Historically, growers in the Werribee Irrigation District extracted irrigation water from the Werribee River, supplemented by groundwater. Because of on going drought, growers in the District received only 40% of their river water entitlement in 2003/04. At the same time, declining groundwater levels resulted in a ban on the use of groundwater to halt the risk of seawater intruding into the aquifer. In January 2004, the Deputy Premier and Minister for Water, John Thwaites, brought forward Melbourne Water's plans for the Werribee Irrigation District Recycled Water Scheme, calling for its completion in time for the 2005 irrigation season.

The works included the construction of a disinfection plant and a five km pipeline, two months of performance testing, endorsement by the Department of Human Services and final sign-off of the Class A recycled water scheme by Victoria's Environment Protection Authority.

WATER QUALITY ISSUE

Recycled water from WTP is produced by an advanced (anaerobic/facultative) lagoon treatment process that incorporates an activated sludge treatment system and extended maturation ponds. The recycled water quality from the huge 55E Pond 10 is highly consistent and closely approaches Victorian EPA Class A guidelines without additional treatment. The entire treatment process from raw sewage to final product adopts the multiple barrier approach and Hazard Analysis Critical Control Point (HACCP) principles.

Up until June 2004, Melbourne Water was confident of being able to achieve Class A water quality with the addition of chlorine disinfection. However, ongoing water quality monitoring found low levels of *Cryptosporidium* when the sensitivity of the testing was increased from 1 oocysts/10 L to 0.2 oocysts/10 L, and maximum concentrations were used instead of medians.

Cryptosporidium test results for water samples collected at the outlet of 55E Lagoon system's Pond 10 from 17 March 2004 to 16 June 2004 were analysed and found that the maximum observed concentration of *Cryptosporidium* was 13.6 oocysts per 10 L with a median of 0.4 oocysts per 10 L. Out of this set of *Cryptosporidium* data, 27% (4 out of 15) were below the detection limit of 0.2 oocysts per 10 L. Based on the analysis of *Cryptosporidium* data, a minimum treatment target of 2-log (99% reduction) *Cryptosporidium* inactivation/removal, in addition to the chlorine disinfection, would be necessary to treat the observed peak concentrations of *Cryptosporidium*. The Department of Human Services (DHS) reviewed the same Cryptosporidium data set and concurred with Melbourne Water's assessment that an additional treatment step capable of achieving a further 2-log reduction in *Cryptosporidium* was required in order to achieve Class A recycled water criteria.

Assessment of Available Treatment Options

Melbourne Water undertook a preliminary investigation of treatment processes capable of achieving a minimum of 2-log *Cryptosporidium* inactivation/removal. The four treatment options considered were as follows:

- UV disinfection;
- Membrane filtration (microfiltration/ultrafiltration);
- Granular media filtration – direct filtration;
- Granular media filtration – slow sand filtration.

The preliminary investigation concluded that all four options were capable of delivering at least 2-log of *Cryptosporidium* inactivation/removal. However, all of the filtration options required at least 12 to 15 months to fully implement, which was well beyond the Stage 1 target completion time of end of October 2004, and therefore unacceptable. On the other hand, UV disinfection had the shortest delivery time of three to six months with a most likely implementation time of three to four months, putting this option within or near the end of October 2004 Stage 1 completion date.

UV disinfection was selected as the preferred treatment option to complement the chlorine disinfection process and produce recycled water that meets Victorian EPA Class A criteria. This decision by Melbourne Water to use UV disinfection proved to be the most straightforward of all the treatment options to design and implement, had the lowest capital cost, occupied the smallest footprint, and remained within the delivery schedule, ensuring completion within the Government's tight timeframe.

UV Design Criteria and Validation

Melbourne Water presented the Department of Human Services (DHS) with the case for complementing the chlorination disinfection process with a UV disinfection facility. DHS responded positively to Melbourne Water's proposal for a UV disinfection facility and stated the following:

DHS agreed with Melbourne Water's assessment that an additional treatment step capable of a further 2-log reduction in *Cryptosporidium* was needed;

DHS required in situ validation of the full-scale UV facility via a seeded challenge study to demonstrate a minimum 2-log reduction in *Cryptosporidium*;

The design of the UV validation programme must be based on the protocols outlined in the USEPA's Ultraviolet Disinfection Guidance Manual (June 2003); and

MS2 bacteriophage (a virus of *E. coli*) was a suitable challenge organism as it is easily grown and commonly used for seeded challenge studies.

Figure 3 compares the relative UV sensitivity of viruses to protozoans based on a 2-log reduction of these microbes.

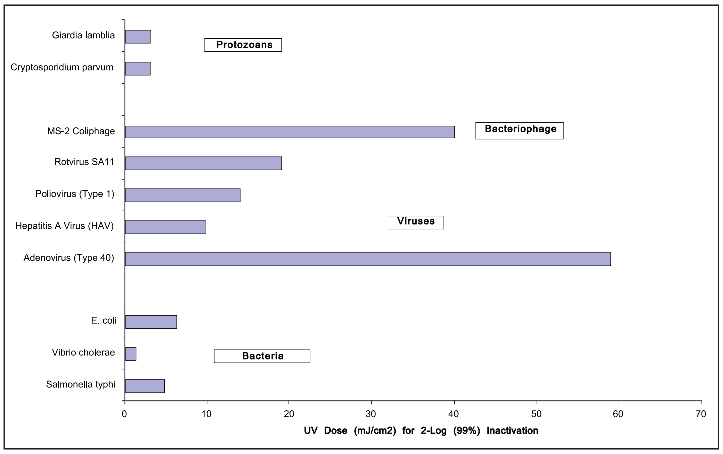

Figure 3 – *UV sensitivity of various microbes (adapted from USEPA 2003)*

Thus, the primary treatment target for the UV disinfection facility was set at 2-log *Cryptosporidium* inactivation as demonstrated by seeded challenge testing using MS2 as the surrogate organism, according to the validation protocols set out in UVDGM. *In situ* seeded challenge testing is presently considered the most rational and widely accepted method of validating the performance of UV disinfection reactors. For the project, the UV disinfection facility was required to achieve at least 2-log *Cryptosporidium* inactivation up to an ultimate design flow of 90 MLD with an initial design flow of 60 MLD for the expected range of 55E Pond 10 water quality. In particular, the following critical water quality indicators were addressed:

- UV transmittance (UVT);
- Total suspended solids (TSS);
- Turbidity; and Calcium, iron, alkalinity, pH and hardness.

Detailed analysis of the available historical water quality monitoring records for 55E Pond 10 was undertaken to define the major design parameters for the UV disinfection facility. The historical water quality from 55E Pond 10 was found to be remarkably consistent, and notably low in suspended solids and turbidity. Analysis of the historical data for the critical water quality indicators determined the following:

- A minimum design UVT of 40% is reasonable and allows sufficient margin for unforeseen variability in the water quality;
- TSS is expected to be below 20 mg/L;
- Turbidity is expected to be below 10 NTU for more than 95% of the time;
- The critical water quality parameters of UVT, TSS and turbidity are comfortably within the known upper limits for UV disinfection performance; and
- The correlation between TSS and turbidity is sufficient to use online turbidity monitoring as a critical control point for UV reactor control.

In addition to the analysis of historical analytical data, the Australian Water Quality Centre in Adelaide performed two sets of collimated beam testing over a wide range of UVT, turbidity and TSS, on water samples collected from the 55E and 25W lagoon systems. The collimated beam tests used standard laboratory-scale UV testing equipment and were conducted according to established USEPA protocols using MS2 bacteriophage. The observed MS2 inactivation rates followed expected UV dose-response curves and there was no evidence of UV shielding by particles/solids.

The collimated beam testing and literature reviews found that UV disinfection could effectively function over the expected range of 55E Pond 10 effluent quality. Collimated beam tests showed a typical UV dose-response for MS2 inactivation. A review of the literature also found that the UV dose-response remains typical for turbidity up to 10 NTU (or about 20 mg/L TSS) and algal counts up to 70,000 cells/mL (EPA 2003). The 55E Pond 10 effluent has been consistently within these values. On this basis, a validation test using MS2 as a challenge organism was considered appropriate for a UV disinfection facility serving the WID Recycled Water Scheme. In addition to the literature review conducted by Melbourne Water, a vendor guarantee was obtained based on the results of a MS2 validation test for the expected range of water quality from 55E Pond 10.

The UV disinfection facility also needed to be fully integrated into the functional requirements for the chlorine disinfection facility. The monthly availability target for the chlorine disinfection facility was 95%. Investigation found that the UV disinfection facility would not impact on the 95% monthly availability of the chlorination facility.

UV Reactor Control Strategies

Control limits were determined and implemented according to HACCP risk management principles to guarantee the production of Class A recycled water and ensure the protection of public health. Proposed critical control limits for the following operating parameters are given in Table 2. Online turbidity measurements were required to provide continuous monitoring of the solids (TSS) entering the UV disinfection facility. Continuous turbidity monitoring is necessary to ensure that the UV reactor operates below the upper limits for TSS given by the UV equipment vendor, results of the collimated beam testing and findings of the literature review.

UV transmittance (UVT) and turbidity/TSS are the main critical control parameters for the UV disinfection process. Both of these were continuously monitored using online instrumentation. The design of the UV facility was based on a minimum UVT of 40% and a TSS of less than 20 mg/L (~10 NTU turbidity). These values were confirmed during MS2 validation testing. The UVT and turbidity were adopted as control variables, and used to trigger alarms whenever these values are approached and potentially shutdown the plant if they are exceeded.

Table 2. *Proposed UV operating control limits*

Operating Parameter	Measurement	Control Limit	Rationale
Flowrate	Flowmeter (online)	Within validated flow range	UV dose
UV Intensity	UV sensor (online)	Within validated UV intensity range	UV dose, lamp status
UVT	UVT sensor (online)	Within validated UV intensity range and not less than 40%	UV dose, lamp fouling/aging,chemical spill
Turbidity	Turbidity meter (online)	Less than 10 NTU (~20 mg/L TSS) at all times. Lower control limit of 6-7 NTU operator surveillance	Elevated risk of off spec recycled water

The design of the UV disinfection system also included consideration of operational and redundancy factors to ensure adequate robustness and reliability of the UV disinfection process. The validation testing was also used to define the UV reactor control strategy to ensure that the UV dose required for 2-log *Cryptosporidium* inactivation target was delivered and verifiable during the production of Class A recycled water. Three possible UV reactor control strategies were considered. The three control strategies differ in their degree of sophistication and complexity. However, all three control methods are equally robust, reliable and capable of delivering the same level of recycled water quality. The simplest control method is the single set-point operation and calculated dose is the most sophisticated control method.

The single set-point control method requires the least amount of commissioning and validation time and effort. Calculated dose is the most sophisticated control method and provides optimum energy use and lamp life. To provide maximum control flexibility and allowance for future optimisation of the UV disinfection facility, Melbourne Water adopted the calculated dose method.

CONCLUSIONS

Melbourne Water found that it is practical to design and operate a full-scale UV reactor with a minimum treatment target of 2-log *Cryptosporidium* inactivation that is reliable, robust and verifiable on unfiltered source water from 55E Pond 10. This conclusion was based on the following findings:

- MS2 inactivation is unaffected in unfiltered water with turbidity up to 10 NTU (about 20 mg/L TSS);
- There is no evidence suggesting that the algal counts in 55E Pond 10 approach a concentration that will impact on MS2 inactivation;
- The demonstration of 2-log inactivation credit for *Cryptosporidium* was achieved using MS2 as challenge organism in collimated beam tests and full-scale experiments;
- Critical UV design parameters of UVT, TSS and turbidity are within the known critical design limits for UV disinfection;
- The UV disinfection facility is expected to have a monthly availability of no less than 95%; and
- All critical UV operating parameters can be measured continuously using online instrumentation, and therefore fit within a HACCP risk management framework.

The recycled water scheme is notable in that:

- An enhanced lagoon treatment system followed by a chlorine and UV treatment barrier has been accredited with Class A recycled water status;
- A state-of-the-art chlorination plant was designed and validated to achieve a 2-log virus reduction credit;
- The chlorine plant was designed to operate in two chlorination modes depending on lagoon performance; and Full-scale testing of the UV treatment barrier using the latest MS2 bioassay techniques was completed to achieve a 2-log reduction credit for *Cryptosporidium*. The authors are unaware of any other UV disinfection facility in Australia that has been validated using UVDGM protocols.
- The testing, specification, purchase and installation of the UV system was all accomplished in a tight timeframe of six months.

Additionally, the low energy usage of the entire disinfection facility contributes to the Western Treatment Plant's commitment of greenhouse neutral operation.

The combined use of two disinfection barriers, i.e. UV and chlorine contact time, is consistent with the concept of multiple barriers to microbial contaminants. A UV and chlorine disinfection system combined with a HACCP risk management approach provides recycled water schemes with a broad spectrum, robust and reliable microbial barrier to ensure protection of public health.

THE AUTHORS

John Poon, is Senior Member of Water Recycling, Strategy and Planning Group, and Melbourne Water Corporation, in early October 2007 John joined CH2M Hill Australia and is based in their Melbourne office (john.poon@ch2m.com.au) as a Principal Technologist; Dr. Alexandra Keegan and Dr. Paul Monis are Research Microbiologists at Australian Water Quality Centre & Cooperative Research Centre for Water Quality and Treatment. They conducted the MS2 seeded challenge studies. Dr. Daniel Deere and Dr. Annette Davison are the Principals of Water Futures and members of the Cooperative Research Centre for Water Quality and Treatment. Water Futures were engaged by Melbourne Water to provide independent oversight and documentation of the UV validation work. Dr. Deere is also a member of the Cooperative Research Centre for Water Quality and Treatment.

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