UV disinfection for reuse applications in North America

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Abstract In an effort to conserve and protect limited water resources, the States of Florida and California have actively promoted wastewater reclamation and have implemented comprehensive regulations covering a range of reuse applications. Florida has a semi-tropical climate with heavy summer rains that are lost due to run off and evaporation. Much of California is arid and suffers periodic droughts, low annual rainfall and depleted ground water supplies. The high population density combined with heavy irrigation demands has depleted ground water supplies resulting in salt-water intrusion. During the past decade, Florida reuse sites have increased dramatically from 118 to 444 plants representing a total flow capacity of 826 MGD. California presently has over 250 plants producing 1 BGD with a projected increase of 160 sites over the next 20 years.

To prevent the transmission of waterborne diseases, disinfection of reclaimed water is controlled by stringent regulations. Many states regulate wastewater treatment processes, nutrient removal, final effluent quality and disinfection criteria based upon the specific reuse application. As a rule, the resulting effluents have low turbidity and suspended solids. For such effluents, UV technology can economically achieve the most stringent disinfection targets that are required by the States of California and Florida for restricted and unrestricted reuse.

This paper compares UV disinfection for wastewater reuse sites in California and Florida and discusses the effect of effluent quality on UV disinfection.

Keywords Ultraviolet disinfection; wastewater reclamation; reuse; Title 22; MS2 phage; virus

Introduction

UV irradiation is a reliable and predictable disinfection technology for the inactivation of bacteria and viruses. Numerous studies have demonstrated that UV can effectively disinfect wastewater without the formation of disinfection by-products (DBP) or residual effluent toxicity (Linden, 1998). Replacement of chlorination/dechlorination with UV disinfection decreases the addition of chemicals to wastewaters that have high total dissolved solids (TDS), a major concern for reuse applications in California.

Reuse guidelines for effluent quality and disinfection criteria

The acceptability of reclaimed water for a specific application is measured by physical, chemical and microbiological criteria. These parameters are in turn influenced by the wastewater source (industrial or domestic) and subsequent treatment processes. Effluent quality limits and wastewater treatment processes are presently regulated for unrestricted reuse applications in 22 states (US EPA, 1992). Either total or fecal coliforms (TC, FC) are used as indicator organisms with a range of acceptable disinfection targets stipulated according to application (Table 1). The State of California Wastewater Reclamation Criteria (Title 22, Division 4, and Chapter 3 of the California Code of Regulations) for unrestricted reuse requires primary, secondary and advanced tertiary treatment with filtration. The Florida Administrative Code 62–610 provides rules for reuse and land application specifying secondary treatment and filtration for all reuse applications. In both states the main reuse categories include agriculture, urban, industrial, recreational, groundwater recharge and augmentation of potable water supplies.

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Table 1 Regulations for Unrestricted Reuse Applications (Crook 1996, US EPA 1992)

State	Irrigation of Raw Food Crops	Indicator/100ml	Turbidity	TSS
California	Yes	≤ 2.2 TC 7 day median	≤ 2 NTU	20–30mg/L
Florida	No	Non Detectable FC 75% samples	≤ 2 NTU	≤ 5mg/L

UV disinfection guidelines – California requirements

Acceptance of UV disinfection technology in California was preceded by extensive pilot and full-scale studies (Snider 1991, CH2M Hill 1992, Kuo 1993, Oppenhiemer 1994). This research demonstrated:

1. No residual effluent toxicity and no significant by–product formation.
2. Reliability and performance are a function of reactor design and effluent quality.
3. Viruses are more sensitive to the UV doses required for coliform inactivation as compared to the standard chlorine doses used to achieve specific coliform targets.

This research confirmed the equivalency of UV and chlorine for inactivation of coliforms and formed the basis of the UV Disinfection Guidelines for Wastewater Reclamation in California (NWRI, 1993). The guidelines for unrestricted reuse effluents require a turbidity of <2 NTU, TC <2.2/100ml and a 4 log inactivation of polio virus. The operational average UV dose of 140 mWs/cm^2 is based on continuous monitoring of lamp intensity, UV transmittance and flow rate. Design specifications include reactor chambers, lamp orientation, and minimum number of UV banks, monitoring with alarm systems, and system redundancy. The California Department of Health Services has adopted the NWRI Guidelines specifying design and performance of UV systems.

Additional pilot studies conducted in California confirmed the impact of TSS and particle size variability on UV dose demand (Table 2).

Relative effectiveness of UV and chlorine on coliforms and viruses

A full-scale study in California utilised parallel treatment trains to evaluate UV and chlorine inactivation of total coliform and seeded MS2 phage (Kuo, 1993). MS2 has a relatively high resistance to both UV and chlorine when compared to pathogenic viruses typically found in wastewater. Secondary effluents with average TSS 16 mg/L (range 5–31) were tested. Standard chlorine and UV doses were selected to achieve a limit of 240 TC/100 ml. Both UV and chlorine doses resulted in a geometric mean of 20 TC/100ml. The data indicate that UV has a significant impact on MS2 (99.9% inactivation) at the doses required to achieve the target TC inactivation (Figure 1). The chlorine dose was able to achieve similar TC targets however; inactivation of MS2 was marginal, ranging from 0.1 to 0.3 log reduction (Figure 2).

Table 2 Averaged effluent quality parameters for coagulated filtered effluents

300 Samples (10 Plants)	UVT (%)	Turbidity NTU	TSS mg/L	Mean Particle size µm	%Particles >31 µm
Average data	69	1.4	2	17	5
Data Range	62–81	0.5–4	0.2–10	12–30	3–20
Plant with lowest UV dose demand	76	< 1	< 1	13	5
Plant with highest UV dose demand	69	0.5–2.2	0.5–6.3	19–30	5–20

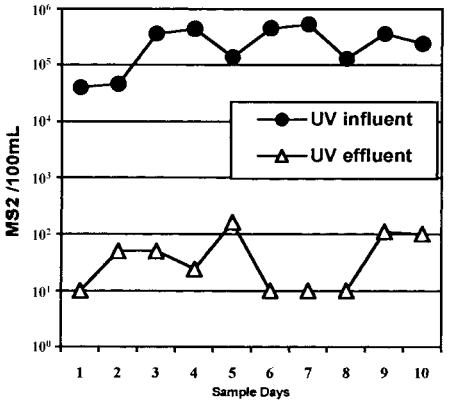

Figure 1 UV inactivation of MS2

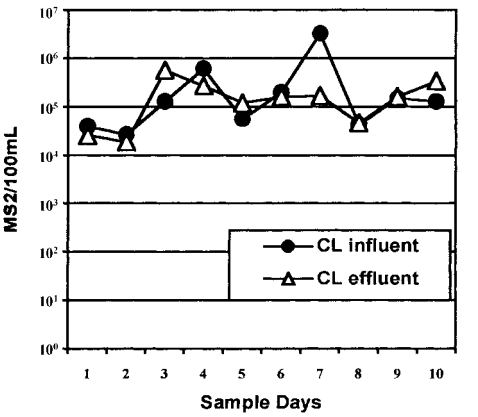

Figure 2 Chlorine inactivation of MS2

A seven-month study was conducted in Florida to determine the UV dose required to meet the State disinfection targets and also to compare the performance of UV and full-scale chlorination. Filtered secondary effluent from an activated sludge process was diverted through the UV pilot unit. The pilot was designed with three UV banks arranged in series. Each bank had 2 horizontal lamp modules containing 2 low-pressure UV lamps. Effluent quality during the study showed an average turbidity of 1.1 NTU (range 0.43–6.2), TSS averaged 1.3 mg/L (range 0–11), and UVT averaged 51% (range 48–55%).

Two UV dose ranges were investigated. The first 31 sample days tested UV doses ranging from 60–67 mWs/cm^2. In this UV dose range, 43% of the samples were non-detectable for fecal coliform (FC). Chlorination during this period achieved 18% non-detectable FC. The UV dose was then increased to an average 95 mWs/cm^2 (range 87–106). This UV dose range resulted in 80% non-detectable FC samples. Figure 3 demonstrates that this UV dose range can reliably achieve the 75% non-detectable fecal coliform target. Over the two UV dose levels tested, UV disinfection exceeded the performance of full-scale chlorination.

A second objective of the study was to determine the efficiency of disinfection technologies for enteric viruses and pathogenic protozoa such as *Cryptosporidium* and *Giardia*. Monitoring for enteroviruses showed low pre-disinfection levels ranging from <1 to <0.02 PFU/100L. After UV disinfection, all samples were <0.02 PFU/100L, the detection limit of analysis. Protozoan analysis was performed on UV influent, UV effluent and chlorinated effluent samples. All samples were analyzed using DAPI viability stain and were reported as non-detectable for *Cryptosporidium* and *Giardia*.

Recent work with UV irradiation of cysts and oocysts indicates that in-vitro tests such as vital stains and excystation methods underestimate the effectiveness of UV to inactivate *Cryptosporidium* and *Giardia* when compared to the results from infectivity tests using neonatal mice and cell cultures methods (Clancy, 1998). It appears that the suitability of in-vitro methods depends upon the method of disinfection used and that the previous reported variations in UV doses required for inactivation may be an artifact of the analytical methods used (US EPA, 1999).

Survey of UV reuse installations

In 1998, a database survey selected UV installations and identified 80 reuse sites in 12 states. Questionnaires sent to the sites achieved a 60% response rate. Table 3 summarizes the plant flows.

Disinfection criteria were site specific, ranging from non-detectable FC to

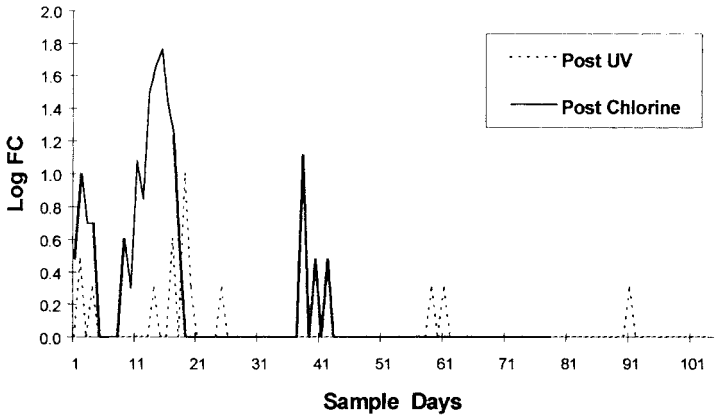

Figure 3 Fecal coliform data after UV disinfection using 2 UV dose levels compared to full- scale chlorination performance. The UV dose averaged 65 mWs/cm^2 for samples 1–31, and the UV dose averaged 95 mWs/cm^2 for the remaining samples

Table 3 Summary of Wastewater Treatment Reuse Sites using UV Disinfection

Plant Flow	Number of Sites	% of reuse sites
≤10 MGD	31	66%
10–20 MGD	11	23%
>20 MGD	5	11%
Total flow 415 MGD	47	100%

≤200 FC/100mL and ≤ 2.2 TC to 23 TC/100mL. TSS criteria varied, 6 sites ≤ 5 mg/L, 5 sites ≤10 mg/L, 9 sites ≤20 mg/L, 27 sites ≤30 mg/L. Turbidity, monitored by 34 plants required flocculation to achieve limits of ≤ 2NTU. All sites had dual media, sand or anthracite filters. The UV design dose for stringent coliform limits averaged 100 mWs/cm^2 (range 60–170). Applications with less stringent coliform limits provided UV doses ranging from 29 to 60 mWs/cm^2. As suggested by the variation in disinfection criteria, the sites represent a variety of restricted and non-restricted applications, ranging from deep well injection to irrigation of landscapes, golf courses and crops. A detailed description of three plants is included below and summarized in Table 4.

1. Elsinore Valley Municipal Water District was the first California plant to install UV for disinfection of reuse effluents. Extensive pilot and full scale UV disinfection studies were performed at this site. The raw influent consisting of residential wastes is prescreened before extended aeration in an oxidation ditch. Clarification is followed by coagulation using an alum polymer blend. The deep bed anthracite filters are gravity flow. Filtered effluent is disinfected using a low pressure UV System (Table 4) and discharged to wetlands. The effluent averages 75%UVT (range 68–77%), TSS average 3 mg/L and turbidity <1 NTU.
2. The Laguna Treatment Plant in Santa Rosa, Ca., processes residential (90%) and industrial wastes (10%). Dry weather flows average 15–20 MGD and the peak wet weather flows are 70 MGD. Primary treatment includes grit removal, flow equalization, and sedimentation. Secondary treatment consists of activated sludge with diffuse aeration and addition of alum before clarification. Anthracite gravity filters produce tertiary effluent for discharge to wetlands and 200 acres of storage ponds with a capacity of 1.5 billion

gallons. Reuse effluents irrigate over 5,000 acres of gardens, farms and golf courses. Wet weather effluent is discharged into the Russian River. Disinfection is achieved using a medium pressure (MP) UV System (Table 4). The disinfection limits are ≤ 2.2TC on a 7 day median. The effluent UVT averages 73% (range 68–77%), TSS average is 1mg/L (range 0.5–6.3) and turbidity is <1NTU.

A pre-design feasibility study was conducted to determine the UV dose requirements for disinfection and to assess disinfection by-product formation (DBP). A comprehensive analysis for DBP on UV treated effluent detected no priority pollutants, volatile or semi-volatile organic compounds after UV doses of 100 and 200 mWs/cm^2.

3. The Homestead WWTP in Florida was designed to produce tertiary filtered wastewater for groundwater recharge. Secondary biological treatment includes a Sequencing Batch Reactor (SBR) followed by an equalization basin, 4 gravity dual media filters (sand/anthracite), UV disinfection and discharge to soak trenches allowing the effluent to percolate into an underground aquifer.

The disinfection criteria are non-detectable fecal coliform in 75% of the samples and the maximum must not exceed 25 fecal coliform/100mL using membrane filtration and mFC media for enumeration. The effluent quality criteria require TSS levels <5ppm and turbidity <2 NTU. The plant is presently meeting all reuse criteria; turbidity is <0.5 NTU, TSS <2 mg/L. Coliform samples are monitored on a daily basis and to date, fecal coliform levels are 97% non-detectable.

Conclusions

Disinfection of wastewater for reuse applications is controlled by stringent regulations that are designed to account for specific usage after discharge. The State of California has adopted the NWRI Guidelines for UV disinfection that stipulate equipment requirements and UV dose delivery. UV dose is selected according to the design specifications for each treatment plant. For Title 22 applications with non-restricted reuse where public exposure may occur, high UV doses ranging from 100 to 140 mWs/cm^2 are required to ensure that the risk of infection due to exposure is less than 1:10,000. California and Florida stipulate filtration for unrestricted wastewater reuse. Such performance criteria ensure the consistent effluent quality necessary to meet the stringent disinfection limits of less than 2.2 total coliform or non-detectable fecal coliform. The present UV installations consistently achieve stringent reuse disinfection targets required by California and Florida. UV disinfection provides a safe and non-toxic alternative to chemical disinfection.

Table 4 Design Parameters for Medium Pressure and Low Pressure UV Systems located in California and Florida

UV Equipment	Elsinore LP	Laguna MP	Homestead MP
Banks	10	12	4
Channels	2	3	1
# Lamps	1200	1080	192
Peak Flow	8 MGD	70 MGD	12 MGD
Average Flow	4 MGD	22 MGD	6 MGD
Design Dose	160 mWs/cm^2	90 mWs/cm^2	120 mWs/cm^2
UV%T	75	60	65
TSS permit criteria	<20 mg/L	<10 mg/L	< 5 mg/L
Turbidity permit criteria	<2 NTU	<2 NTU	<2 NTU
Disinfection Limit	<2.2 TC/100mL 7 day median <	2.2 TC/100mL 7 day median	FC non-detectable 75% samples
Disinfection maximum limit	23 TC/100mL	23 TC/100mL	25 FC/100mL
Application	Wetlands	Irrigation	Groundwater recharge

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