Desalination and Water Treatment
www.deswater.com

26 (2011) 39–44
February

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doi: 10/5004/dwt.2011.2107

Application of UV disinfection in municipal wastewater treatment plants for agricultural use of reclaimed wastewater in Turkey

Serkan Evcimen*, Aslihan Kerc

Marmara University, Faculty of Engineering, Environmental Engineering Department, 34722, Kadikoy/Istanbul, Turkey.
Email: serevcimen@hotmail.com, aslihan.kerc@marmara.edu.tr

Received 25 November 2009; Accepted 4 May 2010

ABSTRACT

In this study, the UV disinfection efficiency based on wastewater quality parameters such as suspended solids, UV transmittance, and initial coliform concentrations (total and fecal coliform) was examined and the appropriate UV-C doses for providing the fecal and total coliform values declared at different regulations and standards for agricultural reuse were investigated. The study was carried out in a UV pilot plant installed at Pasakoy advanced biological wastewater treatment plant, located in Istanbul. The pilot plant was an open-channel system with a capacity of 100 m^3/h. The pilot plant also contained a pressurized sand filter. The effluent taken from the outlet of final clarifiers of Pasakoy WWTP was used in the pilot plant trials. Experiments were conducted with filtered and unfiltered wastewater at various UV-C doses between 20 and 150 mWs/cm^2. The results of the study indicated that the required UV-C dose to achieve a Class 1 water quality according to Turkish Regulations is 140 mWs/cm^2. UV transmittance (measured at 254 nm) and the suspended solids content were determined as the most important wastewater quality parameters affecting the UV disinfection efficiency.

Keywords: Agricultural reuse; Coliform bacteria; UV disinfection; Wastewater

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1. Introduction

Continuously increasing water demands in big cities and water scarcity have been forcing the authorities to look for alternative water sources. The production of wastewater will increase as an outcome of continued urbanization and it is needed to incorporate wastewater into the overall management of water resources [1]. It has been recognized that wastewater reuse or reclamation serves as an efficient and valuable way to cope with the scarcity of water resources and severity of water pollution [2]. Potential applications for wastewater reuse are extremely wide-ranging and include any instance where water is needed for non-potable use. Agricultural irrigation is the largest current use of reclaimed water. As fresh water becomes increasingly scarce due to population growth, urbanization and climate change, the use of wastewater in agriculture will increase even more [3]. The most important issue is public health, when water reclamation is considered [4]. Although conventional processes of wastewater treatment allow a satisfactory removal of the organic load, they appear to be less efficient in removing pathogenic microorganisms [5]. In order to protect human health and also the environment, disinfection of wastewater becomes a necessary part of the treatment [6]. Chlorination and Ultraviolet (UV) disinfection have been the most applied disinfection techniques at full scale. The advantages of applying UV disinfection to enable wastewater to be reused are widely recognized [7]. UV radiation can be considered as the safest and one of the most effective treatment

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*Corresponding author.

Presented at the International workshop on urbanisation, land use, land degradation and environment (ULE 2009), 28 September – 1 October 2009, Denizli, Turkey

techniques to eliminate disease-causing bacteria from wastewater. Not producing any toxic disinfection by-products and the safe and sound operation are the advantages of UV disinfection over chlorination [4,8].

Ultraviolet irradiation is a physical disinfection process that achieves disinfection by inducing photobiochemical changes within microorganisms. An ultraviolet disinfection system transfers electromagnetic energy from a UV lamp to organism's genetic material (DNA and RNA). These materials absorb UV light strongly over the wavelength range of 240 to 260 nm which falls within the UVC region (200–280 nm). The energy absorbed by the nucleic acids causes photoproducts such as thymine dimers on the same nucleic acid strand [9]. If the damage is not repaired, DNA replication is blocked, leading to inactivation of microorganisms [10]. However in some studies, it was shown that total bacterial count in UV treated samples may increase again and this increase is enhanced by high temperature [4]. On the other hand some studies have shown that there is no difference in the regrowth of bacteria after UV disinfection as compared to chlorination [4,8].

Coliform bacteria are the most widely used indicator microorganism to assess the performance of disinfection facilities. Most of the reuse regulations are also based on the coliform counts. However, other microbiological technique like determination of spore forming aerobic bacteria and PCR techniques are also used in current researches [11].

Efficiency of UV irradiation depends on many factors such as wastewater quality, lamp ageing, or the depositions on the lamps. Coliform bacteria located within particles are the most resistant to UV disinfection. Therefore, the performance of clarifiers and the filters prior to UV disinfection is important for the overall disinfection efficiency [12].

Advanced oxidation processes (AOPs), ozonation and membrane techniques are the other possible treatment techniques used for water reclamation. At present, the membrane system remains less competitive than physico-chemical-UV treatment, owing particularly to the high costs of the installation and component replacement [13]. Similarly AOPs and other chemical oxidation techniques are more expensive and not preferred if only disinfection is required.

The aim of this study was to demonstrate the disinfection efficiency of a UV system in Pasakoy wastewater treatment plant (WWTP), located in Istanbul. The microbiological characteristics of the wastewater was not studied in details previously, so the results of this study would also indicate the total and fecal coliform concentration ranges observed in Istanbul wastewaters. Results of the experiments conducted in the pilot plant installed in Pasakoy WWTP with varying wastewater characteristics and operational parameters, were used in the design of the full scale UV disinfection system to determine the required UV dosages for the targeted reuse application.

2. Materials and methods

2.1. Experimental set-up

The UV pilot plant used in this study was manufactured by ITT-WEDECO Company and installed at Pasakoy advanced biological WWTP. Pasakoy WWTP is an extended aeration system with biological phosphorus (P) and nitrogen (N) removal. The feed water for the pilot plant was taken from the collection box receiving wastewater from the final clarifier effluents. The UV pilot plant also contained a pressurized sand filter, which gave the opportunity to conduct the experiments with both filtered and unfiltered wastewater to observe the importance of filtration on UV disinfection efficiency. The pressurized sand filter contained anthracite and sand with a total depth of 100 cm. Fig. 1 shows a schematic view of the pilot plant.

The UV pilot plant was an open-channel system with three UV banks; each consisting of four low-pressure high intensity UV lamps that produce essentially monochromatic UV light at 253.7 nm. The system contained total of 12 UV lamps. The capacity of the pilot plant was 100 m^3/h of wastewater. The experiments were performed during a 9 month period (April 2008–December 2008) with various UV-C doses between 20 and 150 mWs/cm^2. Dose adjustments were made by changing the incoming flowrate and altering the number of banks in operation. Lamp output was set to 80% in the majority of the experiments to simulate fouling effect and the performance of an aged lamp as fouling is known to be an important effect on disinfection performance [14].

Samples were taken from the upstream and downstream of each running UV bank. Sterile bottles were used for sampling. Samples were taken from the mid width and mid depth of the channel and transported to the laboratory for analysis immediately after collection.

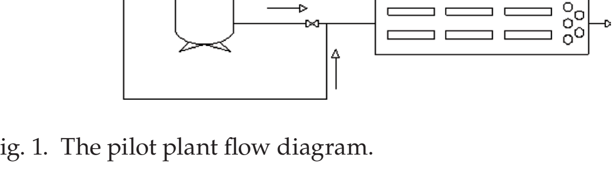

Fig. 1. The pilot plant flow diagram.

2.2. Analytical measurements

Samples were analyzed for UV transmittance (UVT), suspended solids (SS), total coliforms (TC) and fecal coliforms (FC). All analyses were conducted in accordance with the Standard Methods [15]. UVT analyses were performed with a WEDECO model spectrophotometer at 254 nm wavelength. Millipore glass fiber filters were used for SS analyses. Membrane filtration technique was used for bacteriological analyses. Sartorius nutrient pad sets were used for total coliform (Sartorius 14056, Tergitol TTC-NPS) and fecal coliform (Sartorius 14068, M-FC-NPS) analyses. In the bacteriological analyses multiple dilution ratios were used for each sample and duplicate analyses were conducted.

3. Results and discussion

3.1. Microbiological characteristics of Pasakoy WWTP effluent

The results of the analyses demonstrated that the range of TC values of the effluent of Pasakoy WWTP was 60,000–2,120,000 TC/100 ml and FC values varied from 14,000 to 340,000 FC/100 ml. These results revealed an average TC concentration of 282,975 TC/100 ml and an average FC concentration of 78,086 FC/100 ml. Typical levels of TC and FC bacteria in secondary effluents are between 10^5–10^6 and 10^4–10^5 respectively [16]. Collected experimental data indicated that almost all of the samples taken from the effluent of Pasakoy WWTP comply with the values given in the literature for secondary effluent.

During the research period, it was observed that UVT values of Pasakoy WWTP effluent varied between 56 and 70%, and SS varied from 5 mg/l to 36 mg/l, which are similar to typical UVT and SS values for secondary effluents given in literature. Table 1 presents the minimum, maximum and mean values of characteristics of Pasakoy WWTP effluent.

As the measurements cover a period of 9 month, huge variation in the inlet coliform counts and high standard deviation is an expected situation.

3.2. Efficiency of sand filter

In most of the UV disinfection applications, UV systems are coupled with filtration in order to improve the wastewater quality to achieve the target coliform levels. SS and UVT are known to affect the UV disinfection efficiency. Therefore, it is necessary to reduce SS prior to UV disinfection. This enables the optimization of UV system design. In Pasakoy WWTP, it was also decided to use sand filters before the UV disinfection. In this study, in order to monitor the removal efficiency of sand filter, bacteriological analyses were conducted at the inlet and outlet of the sand filter. TC removal efficiency of the sand filter varied between 20 and 62%, while FC removal was between 10 and 68%, depending on inlet wastewater characteristics.

In the pilot sand filter, up to 90% removal of SS was observed. A slight improvement of UVT values was also observed in the sand filter effluent. The wastewater going into sand filter had an average UVT of 60%, while the sand filter effluent had an average UVT of 64%.

3.3. TC and FC removal with UV disinfection

Several experiments were made with different UV-C doses and different wastewater characteristics; such as initial TC and FC amounts, SS and UVT values. Log survival of both TC and FC decreased as the applied UV-C dose increased. Fig. 2 shows the average log survival of TC and FC according to applied UV-C dose.

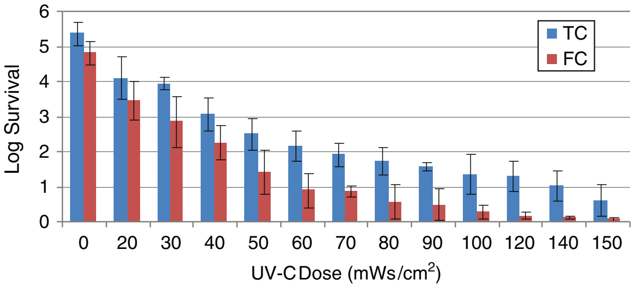

Fig. 2. Dose-Response curve indicating log survival of total and fecal coliforms according to applied UV-C dose.

Table 1
Minimum, maximum and mean values of microbiological characteristics of the Pasakoy WWTP effluent

Parameter	Minimum	Maximum	Mean	Number of measurements	Standard deviation
TC/100 ml	60,000	2,120,000	228,193	43	324,095
FC/100 ml	14,000	250,000	64,597	43	51,060
UVT, %	56	70	61.19	43	3.81
SS, mg/l	5	36	16.02	43	6.81

As it can be seen from Fig. 2, initial FC content of 4.81-log decreases quickly below 1-log at a UV-C dose of 60 mWs/cm^2, while more than 140 mWs/cm^2 is required to diminish the TC content under 1-log.

Irrigation waters are classified into 5 classes based on their fecal coliform content as well as other chemical/physical characteristics according to the current Turkish water pollution control regulation [17]. The experimental results in this study were evaluated based on this classification, and presented at Table 2. The presented data for log survival of FC in the table represent upper 75% confidence interval according to the conducted statistical analyses. Table 2 shows that a minimum design UV-C dose of 140 mWs/cm^2 is necessary to obtain Class 1 irrigation water and a UV-C dose of 60 mWs/cm^2 is adequate to obtain Class 2 irrigation water.

It should be kept in mind that using higher UV-C dosages diminished the probability of reactivation, which can be as high as 1% of the coliform count of the undisinfected water at lower UV-C dosages like 50 mWs/cm^2 [18].

It should be noted that it was aimed to simulate the worst possible conditions in this study. Therefore, most of the experiments were conducted with unfiltered wastewater. Also the power output of the UV lamps was set to 80%, to simulate the performance of an aged lamp. It is evident that Pasakoy WWTP effluent prior to UV disinfection is not suitable for agricultural reuse, but UV disinfection is effective for achieving irrigation standards.

Other than Turkish regulations, experimental data were also compared with WHO guidelines and California water recycling criteria. Fig. 3 presents the upper 75% confidence interval log survival of total and fecal coliforms according to applied UV-C doses. Appropriate UV-C doses to achieve wastewater quality for each standard have been determined.

A UV-C dose of 40 mWs/cm^2 is adequate to comply with the unrestricted irrigation conditions of WHO Guidelines, that limits the fecal coliform content to 103 FC/100 ml [19]. On the other hand, a UV-C dose of 140 mWs/cm^2 is needed to comply with the California water recycling criteria for disinfected secondary-23 category of reclaimed waters, which is one of the most stringent guidelines for irrigation waters that limits the fecal coliform content to 23 FC/100 ml [20].

Although in the literature, it is mentioned that a 4-log reduction can be achieved with a UV-C dose of 90 mWs/cm^2; in this study, a little more than 4-log reduction with such UV-C dose could be obtained [20]. In another study, Sakamoto et al. achieved an effluent quality necessary to meet the stringent disinfection limits of less than 2.2 TC/100 ml with the same UV-C dose [21].

Corresponding chlorine dosages to obtain the same disinfection level obtained by UV disinfection is reported to be between 1–5 mg/l in the literature. Although chlorination is the preferred method in some cases for agricultural and industrial uses, this preference is attributed to economical concerns. When social and health aspects are given greater importance, UV disinfection, which does not produce toxic disinfection by-products, is the preferred method [6,20,22].

Table 2
Required UV-C doses for different irrigation water classes according to Turkish water pollution control regulation (Turkish law no: 20748, 1991)

UV-C dose (mWs/cm^2)	FC/100 ml	Class 1 <2 (excellent)	Class 2 2–20 (good)	Class 3 20–100 (permissible)	Class 4 100–1000 (doubtful)	Class 5 >1000 (unsuitable)
0	78086					X
20	4297.5					X
30	1292.6					X
40	232.0				X	
50	42.5			X		
60	10.3		X			
70	8.2		X			
80	4.9		X			
90	4.7		X			
100	2.2		X			
120	2.1		X			
140	1.9	X				
150	1.4	X				

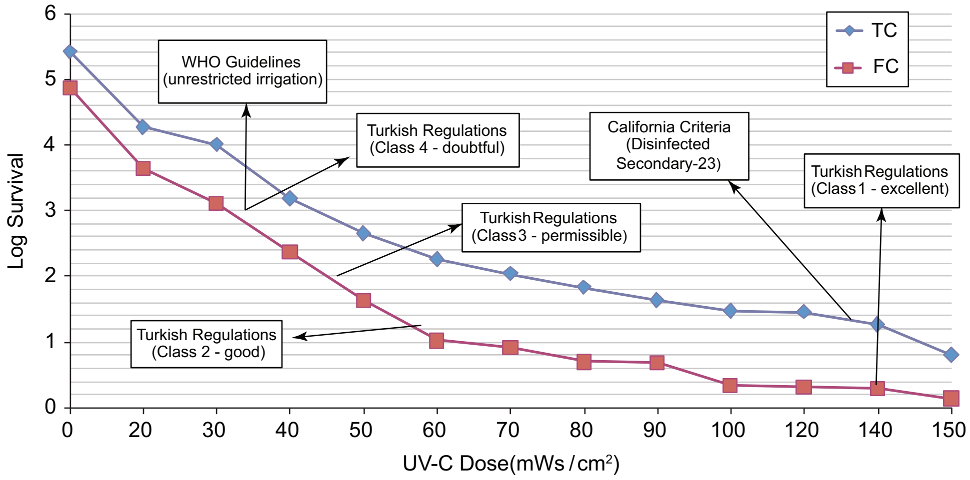

Fig. 3. Upper 75% confidence interval log survival of total and fecal coliforms according to applied UV-C doses.

3.4. Factors effecting disinfection efficiency

SS and UVT are known to be the most important wastewater quality parameters effecting UV disinfection efficiency. During the UV disinfection experiments, these data were also monitored in Pasakoy WWTP. It was observed that other wastewater quality parameters like BOD, COD, nitrogen, phosphate do not affect the UV disinfection efficiency as also noted in the literature. Fig. 4 shows the log survival of TC for wastewaters with different SS contents. Since the experiments were conducted with the real wastewater on site, it was not possible to conduct controlled experiments by changing the SS content and keeping the other parameters constant. Therefore, experimental results were classified into five groups based on the SS content of the effluent. Fig. 3 indicates that greater log-reduction was achieved at the experiments that were conducted with wastewaters that contain less than 5 mg/l suspended solids. The coliform removal efficiency decreases as the SS amounts increase. Suspended particles increase the microbial survival by shielding microorganisms from UV irradiation [23]. Previous researchers also showed that there is a linear relationship between the suspended solids and coliform counts obtained after UV disinfection [12]. Disperse coliform bacteria are readily inactivated with UV irradiation and disinfection problems mostly result from the influence of particle-associated organisms [12]. Using filtration prior to UV disinfection is not only important for the Coliform bacteria, but also for the removal of other microorganisms like bacteriophage [24].

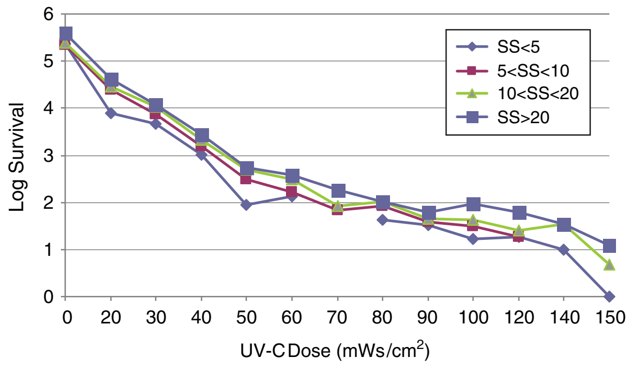

Fig. 4. The effect of suspended solids on UV disinfection efficiency.

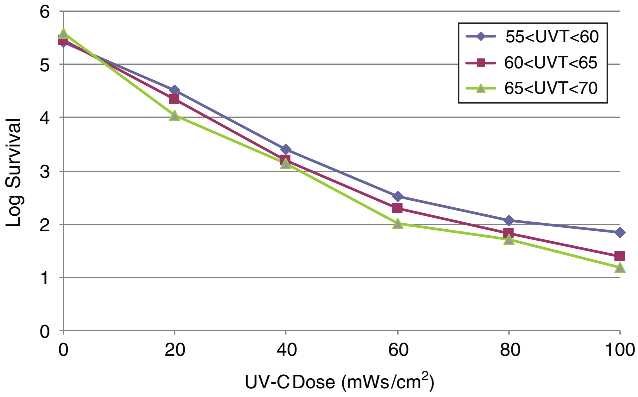

Fig. 5. The effect of UVT on UV disinfection efficiency.

UVT values for the inlet to UV disinfection system varied between 56–70%, which can be accepted as a favorable range for the performance of UV disinfection. Different studies in the literature also cover similar UVT ranges (54–83%) in UV disinfection experimental studies [12,13]. Fig. 5 shows the effect of UVT on disinfection efficiency. It has been clearly observed that, as UVT increases, the efficiency of the disinfection increases. Average TC content of the effluents with UVT higher than 65% which were exposed to a UV-C dose of 20 mWs/cm^2

was 11025 TC/100 ml. As the UVT decreases to 55–60%, the obtained average TC in the effluent was 32550 TC/100mL for the same applied UV-C dose. For UV-C doses higher than 40 mWs/cm^2, effect of UVT was not very significant. TC in the disinfected effluents are presented as log survival values in Fig. 5.

4. Conclusions

This study has demonstrated that Pasakoy WWTP effluent is not suitable for agricultural reuse applications prior to disinfection. Appropriate UV-C dose to achieve a Class 1 irrigation water quality according to Turkish regulations was found to be 140 mWs/cm^2. Results of the experiments indicated that the applied UV-C dose, suspended solids and UV transmittance of water, and initial coliform concentrations are the most important factors affecting the UV disinfection efficiency. UV disinfection efficiency decreased as the suspended solids values increased. The most effective coliform removal was achieved with wastewaters that contained less than 5 mg/l suspended solids. Sand filter was observed to be effective in coliform and suspended solids removal, so it is essential to couple UV disinfection systems with sand filtration.

The results of this experimental study were used as a guidance for the design of the full scale UV system that has been built in Pasakoy WWTP. In the full-scale UV system, a sand filter has been built at the upstream of the UV system; the target effluent FC limit was set as ≤ 2.2 FC/100 ml, and the design UV-C dose was chosen as 90 mWs/cm^2. The experimental results obtained in this study showed that 100 mWs/cm^2 UV-C dose is necessary for unfiltered wastewater with high SS content to obtain ≤ 2.2 FC/100 ml. When effluent of the sand filters are fed into UV disinfection, 90 mWs/cm^2 will be adequate to reach the desired disinfection target.

Acknowledgements

The authors would like to thank ITT-WEDECO company for providing the UV pilot system used in this study.

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