WASTEWATER MATRIX EFFECT ON DISINFECTION WITH LP/UV AND MP/UV RADIATION

Ricardo Salgado[1,2*], Cláudia Hipólito[1], Dina Galhanas[1], Lisete Epifâneo[1,3], João Paulo Noronha[2]

[1] ESTS-IPS, Escola Superior de Tecnologia de Setúbal do Instituto Politécnico de Setúbal, Rua Vale de Chaves, Campus do IPS, Estefanilha, 2910-761 Setúbal, Portugal. *ricardo.salgado@estsetubal.ips.pt

[2]REQUIMTE/CQFB, Chemistry Department, FCT, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal.

[3]SIMARSUL, Sistema Integrado Multimunicipal de Águas Residuais da Península de Setúbal, S.A., Av. Luísa Todi, 300-3º, 2900-452 Setúbal, Portugal.

Abstract

The disinfection of the wastewater effluents is important to reduce the pathogenic microorganism impact in the environment. UV radiation is one of the technologies used for this purposed. The wastewater characteristics, such as dissolved organic compounds or the presence of suspended solids can affect the efficiency of the faecal coliform bacteria removal in the disinfection process by ultraviolet (UV) radiation technology. This study addresses to see the effect of the effluent wastewater matrix in the disinfection by the use of low pressure (LP/UV) and media pressure (MP/UV) lamps. Samples collected in different wastewater treatment plants show different transmittance emission profiles due mostly to the presence of the mixture of dissolved organic compounds with some effect on the faecal coliform bacteria removal.

Keywords: Disinfection; Wastewater; LP/UV radiation, MP/UV radiation; Wastewater matrix effects

1. Introduction

The wastewater reuse has become an important source of water for irrigation of municipal green spaces and cleaning urban areas. It is important to ensure an wastewater quality of the effluent discharged by the wastewater treatment plant (WWTP) for this purpose [1, 2]. The wastewater treatment plants (WWTP) based in activated sludge process only can reduce 2 to 4 log in concentration of pathogens, remaining in the effluent wastewater stream a significant concentration of these microorganisms [3]. To prevent the spread of waterborne diseases and also to minimize the impact in the living organisms and in human health, regulatory agencies require the destruction of pathogenic organisms in wastewaters before reuses or discharge in the natural water bodies.
Bacteria are the most common microbial pathogens found in wastewater. The low pressure ultraviolet radiation (LP/UV) is commonly used as treatment technology installed in the Portuguese WWTP for disinfection of the wastewater effluents before discharge in the natural streams. The presence of dissolved organic compounds not completely removed in the biological treatment can contribute to reduce the efficiency of the disinfection with this technology [4] or to promote the formation of by-products of the oxidation process [5-9]. The presence of suspended solids in the secondary wastewater even in small amounts and the presence of the dissolved organic compounds can affect negatively the UV radiation produced by the lamps. The presence of the suspended and dissolved solids can shield the contact between the microorganisms and the radiation and reduce the disinfection efficiency [10]. These dissolved compounds in the wastewater matrix absorb the UV light, creating a thin layer that bound the UV lamp and avoiding the direct contact of the radiation with the microorganisms. This study addresses to see the effect of the wastewater effluent matrix in the microorganism reduction by the LP/UV and media pressure MP/UV radiation in the disinfection. LP/UV radiation with monochromatic lamp of 254 nm was used in full scale and media pressure UV radiation with a polychromatic lamp was used in lab scale reactor in order to evaluate the wastewater matrix in the microorganism reduction and inactivation.

The disinfection of treated wastewater via ultraviolet radiation is a physical process that principally involves passing a film of wastewater within close proximity of a UV lamp as light source. The efficiency of UV disinfection depends, among other factors, on the physical and chemical water quality characteristics of the wastewater prior to disinfection. UV light (LP and MP lamps) can be an effective disinfecting agent and leave non toxic residual by the use of chemical reagents such as ozone or chlorine [1,7]. This is a disadvantage when wastewater must be piped or stored over significant distances and time (particularly relevant in the reuse of the effluent wastewater) as re-growth of the microbial population can be considered a risk [11, 12]. However, the disinfection with the UV lamps can promote the transformation of the dissolved organic compounds and these changes can be measured by the transmittance.

2. Material and methods

2.1 WWTP selection and sample collection

Two wastewater treatment plants (WWTP 1 and WWTP 2 with average flow of 6773 and 2500 m^3d^{-1}, respectively) have been selected for study the effluent wastewater matrix effect on disinfection, by collecting samples after the secondary settler and before UV lamps and after LP/UV lamp (254 nm, 250 W). The treatment process installed in both wastewater treatment plants was activated sludge but the WWTP 1 receive 20% of industrial wastewater and the rest is domestic wastewater and the WWTP 2 receive 100% of the domestic wastewater. The low pressure UV lamps installed in both WWTP were identical but in the WWTP 1 and WWTP 2 the number of operating hours was 10000 h and 35284 h respectively. The contact time of the wastewater during the disinfection channel with the LP/UV lamps was 21 s and 28 s respectively for the WWTP 1 and WWTP 2.
1L of sample of wastewater effluent before UV and after LP/UV lamp was collected in sterile flasks for analysis. The samples were collected during 3 consecutive weeks and two composite samples every week, before and after UV. A total of 6 samples collected before and after UV were analyzed.

2.2 Full scale disinfection with UV mercury vapor lamp, low pressure (LP)

1L of sample of wastewater effluent before UV and after LP/UV lamp (Trojan UV 3000 plus) was collected for microbiological analysis of total coliform, faecal coliform and E. coli in sterile flasks and to analyze the wastewater absorbance, the samples were filtered by 0.45 µm glass-fiber membrane filters and scanned in the range of the UV wavelength in the spectrophotometer from 190 to 350 nm.

2.3 Lab scale disinfection experiments in UV mercury vapor lamp, media pressure (MP)

700 mL of wastewater effluent before UV was used in the experiments with a lab scale reactor with a medium pressure (MP) Hg lamp, Heraeus Noblelight model TQ 150 (nominal power 150 W) which emits radiation between 200 and 600 nm. The contact time used in the lab scale UV reactor was 30 s. The same microbiological analysis and absorbance scanning was carried out in the samples after exposed to the MP/UV radiation.

2.4 Analytical procedures

2.4.1 Microbiological analysis

The microbiological analysis of the wastewater was carried out in order to determine the total coliform, faecal coliform and E. coli. The total coliform, faecal coliform and E. coli analysis was performed by the determination of the most probable number (MPN) in multiple tube fermentation technique according with the standard methods [13]. For the microbiological determinations in the wastewater, samples were collected before and after the low pressure LP/UV lamps in the full scale plants and also in the lab scale experiment with the MP/UV lamp before and after exposing to the UV radiation.

2.4.2 Spectrophotometric scanning analysis

The samples collected before and after of the low pressure LP/UV lamps in the full scale plants and also in the lab scale experiment with the MP/UV lamp before and after exposing to the UV radiation were scanned in the UV-Vis spectrophotometer (Thermo Scientific evolution 160 UV-vis) to evaluate possible changes in the wastewater matrix before and after being exposed to the UV radiation. Values of transmittance percentage were measured in the UV scanning from 190 to 350 nm and also in visible range from 350 to 650 nm.

2.4.3 Wastewater effluent analysis

The chemical and biochemical oxygen demand, the total suspended solids, turbidity, total phosphorus and nitrogen were also measured in the samples collected before UV according to the standard methods [13].

3. Results and discussion

3.1 Matrix effect on disinfection

The wastewater treated after the activated sludge process, effluent of the secondary settler passes through the LP/UV lamps channel for disinfection. The wastewater quality after the biological treatment and before UV, in the WWTP 1 and WWTP 2, is given in Table 1. The organic matter content in the effluent is very low.

Table 1. Effluent wastewater (before UV) characteristics in the WWTP 1 and WWTP 2.

Parameter	WWTP 1	WWTP 2
SST (mg/L)	9±1	10±1
CBO_5 (mg/L)	4.6±0.9	3±2
CQO (mg/L)	33±3.5	33±4.9
pH	7.1±0.1	6.8±0.2
Turbidity (NTU)	5.5±1.2	6.0±1.9
N Total (mg N/L)	17±1	29±1
P total (mg P/L)	9±1	5.8±0.1
UVT (%)	62.9±0.3	62.2±0.4
$UV_{254\ nm}$	0.18-0.19	0.20-0.21

The treatment efficiency of both WWTP can produce an effluent with good quality. The acceptance transmittance value when the wastewater passes through the UV lamp for disinfection measured at 254 nm (monochromatic lamp) should be higher than 50±5% (254 nm) to achieve a good disinfection performance in the UV radiation.

The wastewater characteristics after the biological treatment can be different due to the presence of dissolved organic compounds. During the biological treatment some of the dissolved organic compounds can be removed biologically but others can be formed during the biological metabolism. These transformations can produce secondary effluents with different transmittance scanning profiles. Measures of the transmittance scanning in spectrophotometer in the UV range (190 to 350 nm) applied to the WWTP 1 and 2 before UV are plotted in Figure 1.

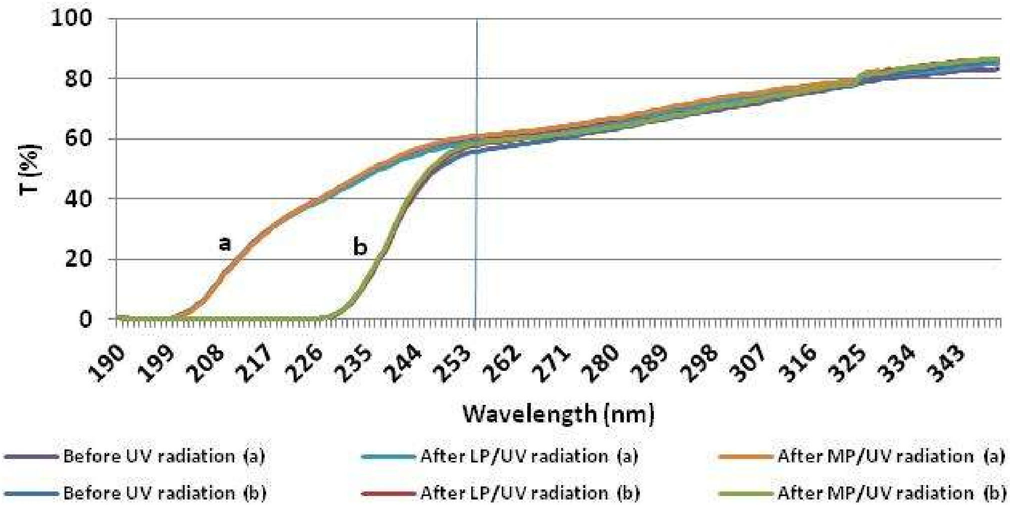

Figure 1. Transmittance (%) of the wastewater after secondary clarifier (before UV radiation) and after LP/UV radiation (full scale results) and after MP/UV radiation (lab scale results) (a) WWTP 1 and (b) WWTP 2.

The effluent wastewater of the WWTP 2 only starts transmit light after 226 nm when compared with the WWTP 1 that starts at 199 nm. The wastewater effluent characteristics can affect the transmittance of the wastewater in each WWTP due to the different mixture of organic compounds present in the wastewater. No significant differences can be found between the wastewater before and after exposure to the LP/UV or MP/UV radiation. 62 % of the transmittance can be detected at 254 nm, independent of the effluent wastewater source, meaning that 38% is absorbed by the wastewater matrix due the dissolved organic compounds present in the wastewater. The presence of 20% of industrial wastewater can change the transmittance characteristics of the wastewater in terms of the dissolved organic compounds (DOC). The wastewater matrix does not have a significant effect the conditions to use the UV radiation as disinfection process for the wastewater.

3.2 Effect of dissolved organic compounds

A very high number of the organic compounds have maximum absorption peaks in the range of 190-300 nm and consequently minimum values of transmittance. By plotting the transmittance variability (difference between transmittance before and after UV related to the transmittance before UV) after passing through the LP and MP/UV radiation, some differences can be found for both lamps, Figure 2.

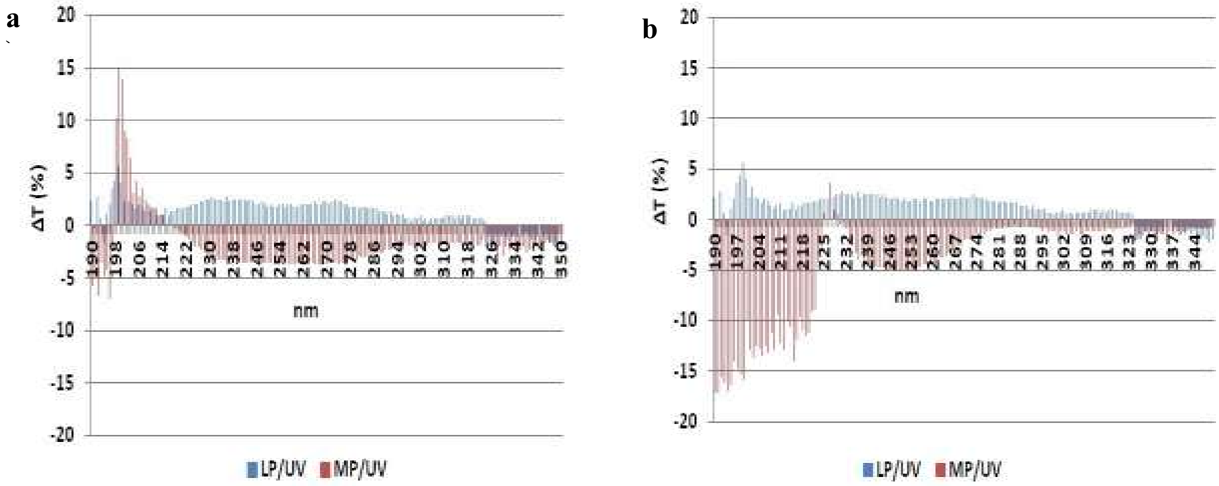

Figure 2. Transmittance variability ($T_{(before\ UV)}$-$T_{(after\ UV)}$)/$T_{(before\ UV)}$), in percentage, of the wastewater before UV radiation and after LP/UV or MP/UV radiation related to the wastewater before UV radiation). (a) WWTP 1 and (b) WWTP 2.

LP/UV lamp can remove transmittance from the wastewater effluent even with the simple emission at 254 nm and the MP/UV can increase the transmittance in ±15 % due to the high emission capacity of the lamp between 200 and 450 nm. These differences are dependent on the wastewater matrix characteristics. The MP/UV lamp can promote the transformation of many dissolved organic compound that absorbed lighter and decreasing the final transmittance (e.g 198-214 nm in WWTP 1) or the transformation can promote the occurrence of new compounds with higher final transmittance (e.g. WWTP 2) which means low absorbance by the new dissolved organic compounds formed. This low absorbance of the wastewater matrix can be related with the destruction of aromatic rings present in the organic molecules or with the oxidation of some functional groups in the organic molecules. These results are in agreement with many studies where the formation of new by-products of photocatalytic process with the use of UV lamps during the disinfection process [4, 8, 9].

3.3 Microbiological removal with UV radiation

Microbiological analysis of the wastewater after passing through the LP/UV lamp in the full scale process and in the MP/UV lamp in the lab scale reactor as well as the removal efficiency in the disinfection is presented in Table 2. The initial concentrations of total coliforms in the wastewater samples varied from 348 to 1609 MPN/100mL, in the WWTP 2 and WWTP 1 respectively.

Table 2. Coliforms (total and faecals) and E. coli MPN/100 mL and removal efficiency (%) in LP/UV and MP/UV lamps for the WWTP 1and WWTP 2.

	WWTP 1				WWTP 2			
	After LP/UV (MPN//100ml)	Removal efficiency (%)	After MP/UV (MPN/100ml)	Removal efficiency (%)	After LP/UV (MPN//100ml)	Removal efficiency (%)I	After MP/UV (MPN//100ml)	Removal efficiency (%)
Total coliforms	542	66	-	-	17	95	78	77
Faecal coliformes	333	85	14	94	0	100	0	100
E.coli	33	70	14	87	0	100	0	100

Both UV lamps can remove almost completely the faecal coliform present in the wastewater when UV radiation is used, however the matrix effect of the dissolved organic compounds and the presence of the industrial wastewater in the influent of WWTP 1 can contribute to decrease the efficiency in the disinfection with the UV technology. The contact time and also number of operating hours of the lamps and cleaning maintenance of the lamps can also contribute to reduce the performance of the UV radiation in the disinfection, but in this study this effect was not observed. Maintenance costs of this technology has become an disadvantage for the use this technology in the wastewater disinfection and other solutions are becoming promising such as ozone and chlorination of the WWP effluents.

4. Conclusions

The wastewater matrix characteristics changes from one to another WWTP, depending of the industrial wastewater presence in the plant. The transmittance of the wastewater in low wavelength can be very small but in the 254 nm good conditions can be achieved for disinfection using UV radiation. The use of LP/UV lamps (monochromatic lamp) can remove a small fraction of transmittance (± 5%) and the use of MP/UV lamp (polychromatic lamp) can remove or increase the transmittance of the wastewater in ± 15%, depending on the wastewater matrix. The microbiological removal of faecal coliforms and E. coli is very effective with the use of LP/UV or MP/UV lamps. The use of LP/UV lamps for disinfection can be more selective for microbiological inactivation of pathogenic bacteria. The use of MP/UV lamps is not selective to promote only the microbiological inactivation but also to promote the transformation of dissolved organic compounds. In this case, the WWTP 2 produced new compounds with higher transmittance after passing through the MP/UV lamps meaning that low absorbance by the wastewater in the wavelength range of 190 to 225 nm and 232 to 274 nm.

References

[1] Xu, P., Janex, M., Savoye, P., Cockx, A., Lazarova, V., (2002). Wastewater disinfection by ozone: main parameters for process design, *Wat Res*, 36, 1043–1055.
[2] Liberti, L., Notarnicola, M., Petruzzelli, D. (2002). Advanced treatment for municipal wastewater reuse in agriculture. UV disinfection: parasite removal and by-product formation, *Desalination*, 152, 315-324.
[3] Lydakis-Simantiris, N., Riga, D., Katsivela, E., Mantzavinos, D., Xekoukoulotakis, N.P. (2010) Disinfection of spring water and secondary treated municipal wastewater by TiO2 photocatalysis, *Desalination,* 250, 351–355.
[4] Salgado, R., R., Marques, R., Noronha, J.P., Carvalho, G., Oehmen, A., Reis, M. A. M. (2012), Assessing the removal of pharmaceuticals and personal care products in a full-scale activated sludge plant, Environ. Sci. Poll. Res., 19 (5), 1818-1827.
[5] Sun, Y., Wu, Q., Hu, H., Tian, J., (2009). Effect of bromide on the formation of disinfection by-products during wastewater chlorination, *Wat Res*, 43, 2391–2398.
[6] Liu, J., Li, X., (2010). Biodegradation and biotransformation of wastewater organics as precursors of disinfection byproducts in water, Chemosphere 81, 1075–1083.
[7] Buth, J.M., Ross, M.R., McNeill, K., Arnold, W.A.. (2011). Removal and formation of chlorinated triclosan derivatives in wastewater treatment plants using chlorine and UV disinfection, Chemosphere 84 (2011) 1238–1243.
[8] Salgado, R., Pereira, V.J., Carvalho, G., Soeiro, R., V. Gaffney, V., Almeida, C., Cardoso, V.V., Ferreira, E., Benoliel, M.J., Ternes, T.A., Oehmen, A., Reis, M.A.M., Noronha, J.P. (2013), Photodegradation kinetics and transformation products of ketoprofen, diclofenac and atenolol in pure water and treated wastewater, *J. Hazard. Mater*, 244-245, 516-527.
[9] Pablos, C., Marugán, J., van Grieken, R., Serrano, R.E., (2013). Emerging micropollutant oxidation during disinfection processes using UV-C, UV-C/H2O2, UV-A/TiO2 and UV-A/TiO2/H2O2, *Wat Res*, 47,1237-1245.

[10] Brahmi, M., Belhadi, N.H., Hamdi, H., Hassen, A., (2010). Modeling of secondary treated wastewater disinfection by UV irradiation: Effects of suspended solids content, *J. Environ. Sci.*, 22(8) 1218–1224.
[11] A. Mofidi, A. A., Rochelle, P.A., Chou, C.I., Mehta,, H.M. (2002), Bacterial Survival After Ultraviolet Light Disinfection: Resistance, Regrowth and Repair, American Water Works Association, American Water Works Association Annual Conference and Exibition.
[12] Poepping, C., Beck, S.E., Wright, H., Linden, K.G., (2014). Evaluation of DNA damage reversal during medium-pressure UV disinfection, *Wat res,* 56, 181-189.
[13] APHA, 1998. Standard Methods for the Examination of Water and Wastewater, 20^{th} ed. American Public Health Association, Washington DC, USA.

Acknowledgements

Instituto Politécnico de Setúbal (IPS) and Escola Superior de Tecnologia de Setúbal (ESTSetúbal) is gratefully acknowledged for the financial support of this project, 3-CP-IPS-07-2009. Simarsul, in particularly Eng Cristina Santos, is thankfully acknowledged for assistance with sampling of the WWTPs.