Optimum location of an ultraviolet step in a surface water treatment plant

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** SEDIF

Abstract To meet the new DBP rules, ozone doses will have to be minimized to control bromate formation. In some surface water treatment plants, this situation may become of concern, since disinfection will have to be maintained at the current level. Alternative disinfection means such as UV have therefore to be evaluated, and this study was designed to evaluate the impact of MP-UV on water quality parameters such as atrazine, BDOC or nitrites, to determine whether such a treatment step should be inserted before or after the current GAC filtration unit. According to the results shown here, this question is not an issue under conditions needed for *Cryptosporidium* inactivation.

Keywords *Cryptosporidium*; disinfection; pesticides; spores; ultraviolet

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Introduction

Water treatment professionals have to deal with positive (i.e. reduction of pathogen risks) and negative (i.e. increased chemical risks) health effects of drinking water disinfection. This situation becomes of concern in view of the proposed standard of 10 µg/L for bromate ions (US.EPA, 1990; EU.C, 1998).

In the case of the Neuilly surface water treatment plant, which delivers water to 1,260,000 consumers of the suburbs of Paris, the current ozonation practices led to the formation of bromate ions often above the new standard. The Neuilly-sur-Marne treatment plant abstracts water from a highly developed watershed, subject to agricultural, industrial and municipal effluents, resulting in a high load of human pathogens, and the current level of disinfection will have to be maintained. The raw water is directly abstracted in the plant, and currently treated by coagulation, flocculation, settling, rapid sand filtration, ozonation, biological filtration through granular activated carbon, and chlorination. Ozonation is the only step responsible for *Cryptosporidium* inactivation and also bromate formation. Since the ozone doses must be lowered to meet the new bromate standard, it has been decided to study the possibility of implementing a new disinfection step in the treatment line, to compensate the lower ozone doses.

According to Malley (2000), Clancy (2000) and Sommer *et al*. (2000), UV light is able to inactivate parasites such as *Cryptosporidium*, viruses, spores and bacteria. The benefit of this technology also includes the absence of bromate or THM formation. Hence, UV steps appears to be a suitable and cost-effective solution. In the European and French context, one has, however, to demonstrate that this new step will not give raise to higher pesticide oxidation product concentrations in the treated water, since these are also considered as pesticides, with an applicable MCL of 0.1 µg/L. Likewise, one has to demonstrate that UV light will not form biodegradable organic matter, which would have to be further treated in the line. The objectives of the study were:

- to check the inactivation of target microorganisms such as *Cryptosporidium* and MS-2 phages using medium pressure mercury lamps (MP-UV);

- to measure the impact of MP-UV on atrazine and desethyl-atrazine (DEA)
- to measure the impact of MP-UV on nitrites
- to measure the impact of MP-UV on the biodegradable organic carbon (BDOC)

As a conclusion to these assays, the study will enable the authors to determine whether the MP-UV step should be installed:

- after sand filtration and thus, before granular activated carbon filtration (GAC), which could then remove BDOC or adsorb pesticide degradation products;
- or after GAC filtration, if the water is suitable for direct distribution.

Material and methods

Influent water quality

The water quality under survey is that at the sand filter effluent, with an average UV transparency of 96% per meter. Turbidity is always inferior to 0.05 NTU and TOC content is less than 2.0 mg.C/L. The nitrate concentration varies from 15 mg/L to 30 mg/L and pollution by pesticides such as Atrazine can reach 1 µg/L.

Pilot unit

UV contactor geometry was cylindrical and the lamp was parallel to the flow. The MP-UV unit had two different medium pressure mercury lamps of 20 cm in length: standard and free ozone. Both bulbs were made with standard quartz but one of them was covered by an additional free ozone quartz sleeve. It was spiked with titanium, and it cut wavelengths inferior to 220 nm which could be responsible for by-product formation. The standard lamp delivered 12% of its energy between 220 and 280 nm (UV-C), whereas the free ozone lamp delivered only 4%. Their spectrums were polychromatic with a maximum level around 254 nm.

A calibrated 3WLX sensor controls the lamp power at 254 nm. It is placed directly on the pilot chamber in front of the quartz sleeve window at a fixed position.

Fluence calculation

The calculation method is developed from Reyer (1997) and Bolton (1999, 2000). The formula takes into account a single source, with any wave surface and each parameter being wavelength dependent.

$$F_i = \frac{P}{S}\exp(-kl) \quad (1)$$

where: F_i is the flux on (i) point (W/m^2); P the source power (W); S: wave surface (m^2); : absorption coefficient (m^{-1}); and l: path length (m).

The pilot lamp is described by a succession of source points, the fluence rate being the summation of all rays produced by each source. All germicidal power of the UV lamp was reduced to 254 nm wavelength. Since the pilot has a cylindrical geometry, the fluence rate is calculated on the height and radius of the cylinder (r,z) plan. After integration of the direct ray contribution (quartz sleeve interface effects are omitted) the Fluence rate E′ reads:

$$E'(r,z) = \frac{P_l}{4\pi L}\int_{z_{min}}^{z_{max}} \frac{1}{R^2}\exp(-\frac{k(r-e)}{r}R)dz' \quad (2)$$

where P_l is the germicidal power per lamp length (W/m); L: lamp length (m); R: distance of point source (m); e: quartz sleeve radius (m); r: minimum length to lamp axe (m); z_{min}: first point source position; and z_{max}: last point source position.

For the reflected ray contribution, the same formula was used. Then the reflected contribution to the fluence rate balance by a reflection coefficient (C_r) is:

$$E_r'(r,z) = C_r.E'(D-r,z) \quad (3)$$

Lastly, the total fluence rate on one point reads:

$$E_T'(r,z) = E'(r,z) + E_r'(r,z). \quad (4)$$

When the fluence rate was calculated for all points, the fluence was obtained by summation, weighted by time and volume, of each fluence rate received.

Analyses

Cryptosporidium parvum oocysts used for this study were obtained from the INRA laboratory in Tours (France). They were counted using a Chemscan appartus, their viability was quantified by infection on human intestine cells HCT8 following the method developed by Slifko *et al.* (1997).

Chromatographs were used for chemical analyses after the NF EN ISO 11369 method. TOC was measured using the NF EN 1484 (T90-102). Biodegradable organic carbon was measured using the XPT 90-319 method.

Results

Cryptosporidium inactivation

Cryptosporidium oocysts were spiked in the influent water to reach 5×10^5 oocyts/L, knowing that roughly 10% are infectious before treatment. *Cryptosporidium* inactivation reached all-time quantification limits (i.e. 3 to 3.5 log inactivation on average, depending on the number of infectious oocysts in the oocysts solution), for fluence ranging from 100 to 1,000 J/m^2. Two assays at two temperatures were conducted with the standard lamp and one assay was done with the free ozone lamp. More than 2.7 log units of inactivation was obtained in whatever conditions. These results are in accordance with Clancy (2000).

MS2-phage inactivation

MS2 Bacteriophage was spiked from 10^6 up to 10^{10} phages/mL, according to the assay under consideration. MS2 bacteriophage inactivation data (Figure 1) showed a good correlation with Sommer *et al.* (2000) results with a minimum near 2 log units at 400 J/m^2. Moreover no temperature dependence was demonstrated. In other respects, low wavelength disinfection contribution suppression under 220 nm weakly affected the global inactivation even if the low wavelengths' efficiency was demonstrated by Linden *et al.* (2000) for these organisms.

Atrazine degradation and DEA formation

Atrazine and DEA were spiked to reach 5 µg/L in the feed water to observe the degradation (Figures 2 and 3). The degradation of both atrazine and DEA is linked with the fluence rate by a log-linear relationship.

Atrazine is mainly degraded into hydroxyatrazine, and possibly DEA. However, this latest molecule is further degraded, and no increase is observed. In opposition, an increase in hydroxyatrazine is observed, showing that 90% of influent atrazine is converted into hydroxyatrazine. This observation is in accordance with Bourgine *et al.* (1997).

Nitrite formation

As a result of agricultural activities, nitrate ions are present in the raw water, usually between 20 and 40 mg/L. The results show that MP-UV reduce nitrate in nitrites, which may become of concern if the standard of 0.1 µg/L is exceeded in the treated water. The

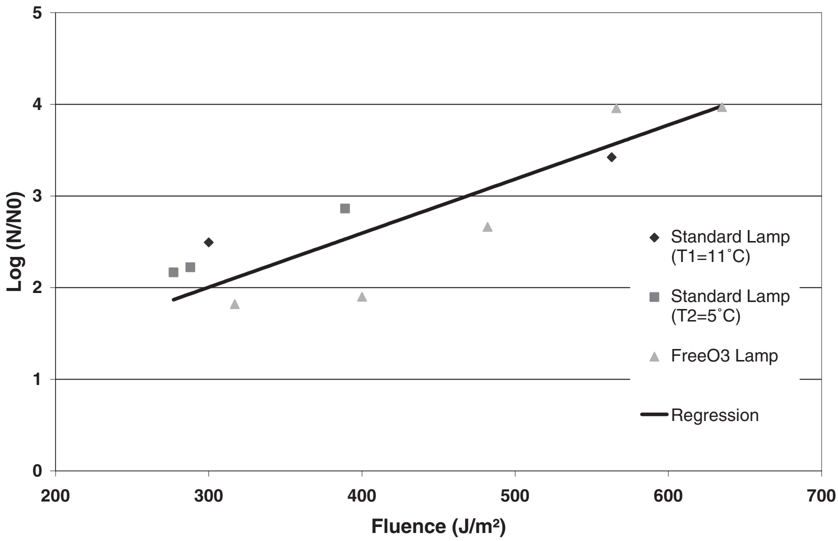

Figure 1 MS2-phages inactivation

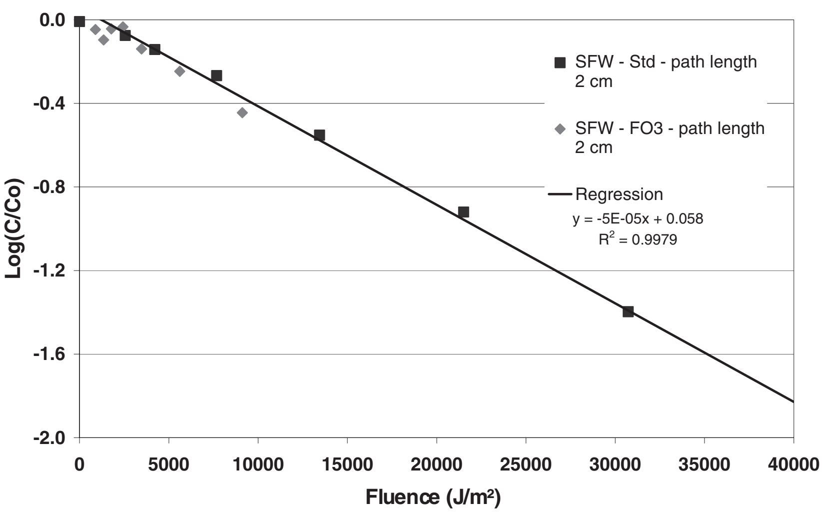

Figure 2 Effect of MP-UV on atrazine

authors' experiment demonstrates that this limit is exceeded when the fluence rate is above 400 J/m^2. This phenomenon can also be controlled using a "Free ozone" Quartz sleeve, as shown on Figure 4.

BDOC formation

The question of BDOC formation can be raised, and this formation was measured as a function of fluence rate (Figure 5). The results show no significant trend for the impact of MP-UV on BDOC formation. This observation is consistent with the findings of Camper *et al.* (2001).

Discussion and conclusions

According to the new DBP rules, the bromate concentration in drinking water is no longer allowed to exceed 10 µg/L. For utilities such as SEDIF, where Ozone is used as an inactivation step for *Cryptosporidium* control, this situation is of concern. Studies have

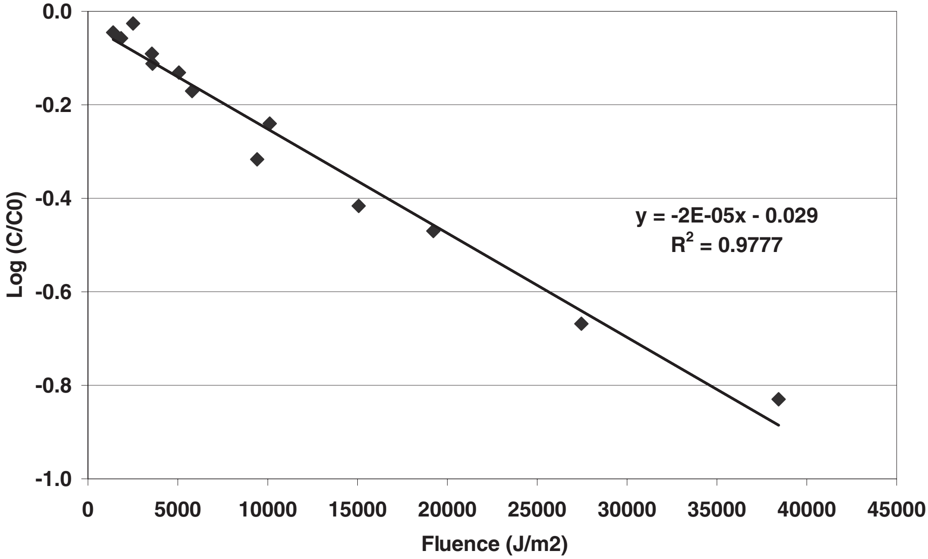

Figure 3 Impact of MP-UV on DEA

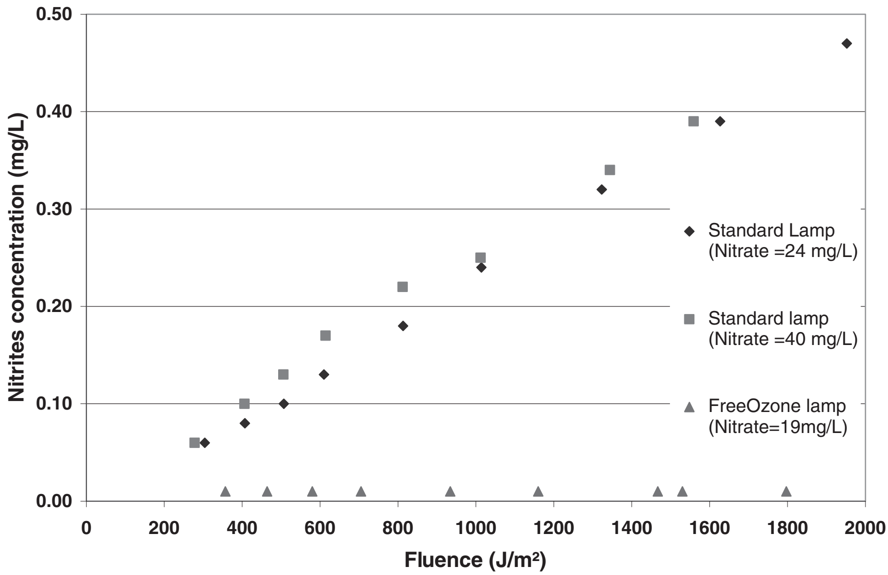

Figure 4 Impact of MP-UV on nitrite formation

demonstrated that bromate control options cannot guarantee that this MCL will be respected all the time when disinfection remains the first objective (Dile-Mary, 2001).

Hence, other disinfection means have to be considered, and UV appears to be a viable alternative. This study was designed to assess the impact of a new MP-UV step in the existing treatment line of the Neuilly-sur-Marne Water Treatment Plant, which includes clarification, rapid sand filtration, ozonation, GAC filtration and final chlorination. Table 1 below summarises the results of the tests carried out to evaluate the impact on microbiological parameter, and other parameters such as pesticides (represented here by atrazine and DEA), nitrites and BDOC.

The results widely confirmed the earlier literature on the benefits of MP-UV in parasite and virus control. With regards the impact of UV on pesticides, it is demonstrated here that

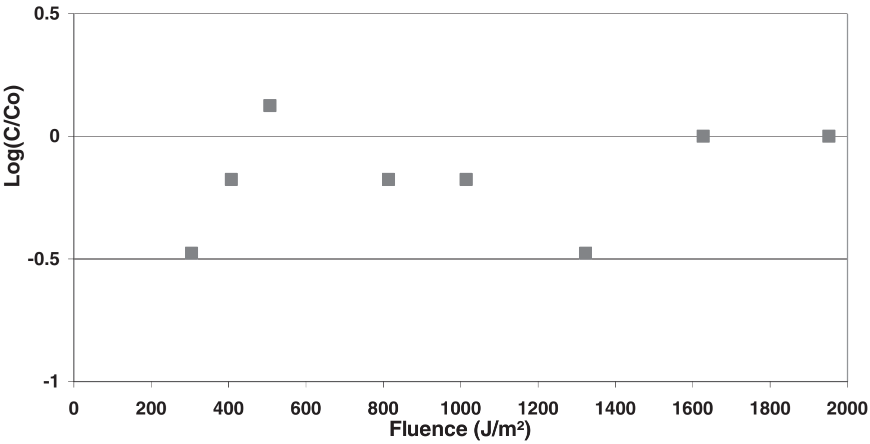

Figure 5 Impact of MP-UV on BDOC

Table 1 Impact of MP-UV on various water quality parameters for a fluence rate between 200 and 400 J/m^2

Parameter	Impact	Comment
Cryptosporidium	Significant	> 3 log in all cases
MS2 Phages	Significant	1 to 4 log
Atrazine	Not significant	Degradation observed for higher fluence rates
DEA	Not significant	Degradation observed for higher fluence rates
Nitrites	Not significant	Using a free ozone quartz sleeve
BDOC	Not significant	

MP-UV does not have an impact at fluence rates suitable for disinfection purposes. No impact on BDOC levels has been shown. As a consequence, a new MP-UV could be inserted either before or after the GAC filtration step, since no undesirable by-product will have to be eliminated by adsorption. Research is still underway to further detail the impact of MP-UV on water quality parameters.

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