

Ozone disinfection: main parameters for process design in wastewater treatment and reuse

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ABSTRACT

Wastewater disinfection by ozone was investigated at pilot and full scale on different wastewater effluents and two types of ozone reactors. It was demonstrated that water quality and, in particular, suspended solids and organic content strongly influence the required ozone dose for a given level of disinfection. The increase in contact time and residual ozone concentration did not improve the log removal of viruses and bacteria. However, the 'Ct' approach, commonly applied in drinking water treatment can be used for wastewater ozonation, if a sufficient ozone dose can be transferred to the effluent resulting in an ozone residual which can be measured. These considerations should be taken into account for the improved design of ozonation facilities. It should be underlined that short contact times are only possible if fast balanced distribution of the ozone dose is achieved as rapidly as possible, in order to satisfy fast chemical reactions (colloidal matter destabilisation, zeta potential, etc.) and enable a uniform distributed ozone residual for the slower reactions (disinfection, oxidation of micropollutants, etc.).

Key words | modelling, ozonation, process design, toxicity, wastewater disinfection

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INTRODUCTION

Ozone has been proved to be one of the most effective disinfectants and is widely used to inactivate pathogens in drinking water, especially in Europe, the USA and Canada (Xu *et al.* 2002). In the field of wastewater treatment, ozonation is widely used for colour removal and oxidation of refractory organics (chemical oxygen demand (COD) reduction) in industrial wastewater treatment, as well as for final disinfection of municipal effluents (Paraskeva & Graham 2002). Wastewater treatment by ozone is implemented in Canada, France, Germany, Japan, Korea, the UK and the USA.

Ozone is a strong oxidising agent, effective in destroying bacteria, viruses, but also cyst-forming protozoan parasites like *Giardia* and *Cryptosporidium*, which are particularly resistant to most other disinfectants (WEF 1996). The germicidal effect of ozone consists of totally or partially destroying the cell wall, resulting in microorganism lysis. In addition, ozone breaks chromosomes, nitrogen-carbon bonds between sugar and bases, DNA hydrogen bonds, as well as

phosphate sugar bonds leading to depolymerisation and leakage of cellular constituents and irreversible enzyme inhibition. Two mechanisms for ozone disinfection occur: a direct oxidation of compounds by the ozone molecule and a reaction involving the radical products of ozone decomposition, principally believed to be the hydroxyl radical. This radical is highly reactive and has a life span of only a few microseconds in water. The predominant reaction will depend on the wastewater characteristics.

However, it is now known that organic matter partially transforms ozone into hydroxyl radicals (Buffle 2005). It is therefore possible to assume that wastewater ozonation is, in fact, per se, an advanced oxidation process (AOP).

Many researchers initially sought to achieve a measurable level of dissolved ozone residual in treated wastewater, which resulted in high ozone dosages that were not economically feasible. Recent studies have indicated the good disinfection efficiency at low transferred ozone dosages and

very short contact time for the removal of bacteria and viruses (Lazarova 2000; Liberti et al. 2000; Savoye et al. 2001; Xu et al. 2002; Buffle 2005). Moreover, an increasing interest has been reported in ozone efficiency for the oxidation of organic micropollutants (Wert et al. 2007; Gagnon et al. 2008; Leong et al. 2008).

In this context, the present study investigates the main factors related to ozone disinfection performance, for the purpose of facilitating its design and application to wastewater disinfection.

MATERIALS AND METHODS

Experiments were performed in continuous-flow pilot plants with different types of effluents to evaluate ozone disinfection performance on different target microorganisms and other effects on the quality of wastewater (Table 1). To investigate the influence of wastewater quality on disinfection performances, additional tests have been performed in full-scale wastewater treatment plants in France, Switzerland and elsewhere. Also, pilot tests with two different types of ozone reactors, one with a very short residence time and as reference, a classical bubble column with porous diffusers, were conducted simultaneously with the same wastewater in order to evaluate the influence of the residence time on disinfection efficiency.

The transferred ozone dose (TOD) was used as a descriptive parameter throughout the study. Due to non-negligible solubilisation of the ozone (inert) carrier gas, it is defined on an in/out gas mass-flow basis as follows:

$$\text{TOD} = (Q_{\text{gas}}*[O_3]_{\text{g, in}} - Q_{\text{gas}}*[O_3]_{\text{g, out}})/Q_{\text{liq}} \quad (1)$$

where Q_{gas} and Q_{liq} are gas and water flow rates, respectively, $[O_3]_{\text{g in}}$ is the ozone concentration in the feed gas to the column, $[O_3]_{\text{g out}}$ is the ozone concentration in the off-gas leaving the column.

Ozone demand of the investigated effluents was determined with two parameters: X , the immediate ozone demand; and k , the decay kinetic constant, due to overall ozone consumption by moderate or slow reactions. Both values have been calculated from the plot of the residual ozone versus TOD. When the TOD exceeds X , residual ozone appears in the effluent and its concentration increases with increasing TOD. The slope of the plot (Kd) is the function of the hydraulic residence time in the reactor, its hydraulic characteristics and k . Kd can be determined according to the following equation:

$$Kd = \frac{1}{\left(1 + \frac{kT}{n}\right)^n} \quad (2)$$

where Kd is the first order decay constant, in min^{-1} , T is the mean hydraulic retention time (HRT) in the column (min),

Table 1 | Wastewater characteristics

Parameter	Pilot studies			Full-scale
	Tertiary effluent		Secondary effluent	Tertiary effluent
	Pilot 1	Pilot 2	Pilot 3	Plant 1
Suspended solids, mg/L	2.3 (<1–4)	5 (3–6)	18 (7–> 20)	1.7 (0.2–9.6)
COD, mgO ₂ /L	30 (24–38)	36 (26–56)	71 (40–> 100)	36 (6–86)
TOC, mg/L	8 (5.5–10.2)	<10 (<10–14)	26 (<10–> 20)	–
UV 254 abs, m ⁻¹	15.5 (12.5–20.8)	22.2 (17.4–20.8)	34.9 (>20–> 40)	–
pH	7 (6.9–7.2)	7.3 (7.3–7.4)	7.5 (7.4–8.0)	8.1 (7.4–8.5)
Faecal coliforms, log CFU/100 mL	–	3.6–4.5	4.3–6.5	–
<i>Escherichia coli</i> , log CFU/100 mL	2.7–4.3	–	–	5.1 (2.9–6.0)
<i>Clostridium</i> , log CFU/100 mL	–	3.0–4.5	3.6–5.5	–

TOC: total organic carbon.

n is the number of completely stirred tanks in series (CSTR), measured by hydraulic tracer tests.

To investigate the influence of wastewater quality on disinfection performances, additional tests have been performed in a full-scale wastewater treatment plant in France with a treatment capacity of 97,000 p.e., 16,400 m³/d. The treatment train includes activated sludge (N + P removal), pressurised tertiary sand filtration and ozonation (0.5–5 kgO₃/h). The design ozone dose is 10 mg/L with 20 min contact time.

For the microbiological analysis, grab samples were taken into 200 mL sterile glass bottles, kept at 4 °C until use for 24 h. Faecal coliforms (FC) (thermotolerant coliforms), *Escherichia coli* and *Enterococci* numerations were conducted with the microplate technique according to NF EN ISO 9308-1 and NF EN ISO 7899-2 standardised methods. Spores of *Clostridium perfringens* are measured according to the French AFNOR V59-107 standardised method.

The toxicity of ozonated effluents was evaluated by the LuminoTox photosynthetic enzymatic complexes (PECs) test, which consists of a portable biosensor that indicates the presence of toxic chemicals in water. It uses PECs that are membranes isolated from chloroplasts. The PECs are as simple to use as a chemical, but react more rapidly than a living organism because toxic compounds do not have to penetrate the cell wall of an organism (inhibition of the

photosynthetic electron chain). When stimulated by light, the PECs emit fluorescence, whose decrease is the result of the presence of toxic contamination, expressed as per cent inhibition.

The immunotoxicological effects of wastewater ozonation on freshwater mussels were investigated in primary effluents from the wastewater treatment plant of a large North American city (Gagné et al. 2008) and secondary effluent (Müller et al. 2009). Mussels were exposed to increasing concentrations (0, 1, 3, 10 and 20% v/v) of the effluent before and after ozone treatment (TOD of 10 mg/L) in a continuous flow-through laboratory reactor for 4–7 weeks. Rainbow trout were also investigated (Hébert et al. 2008).

RESULTS AND DISCUSSION

Influence of wastewater quality on disinfection efficiency

The experimental results obtained at pilot scale on different wastewater effluents confirm the efficiency of ozone for wastewater disinfection (Figure 1). Depending on the quality of the effluent, a TOD of between 2 and 15 mg/L was

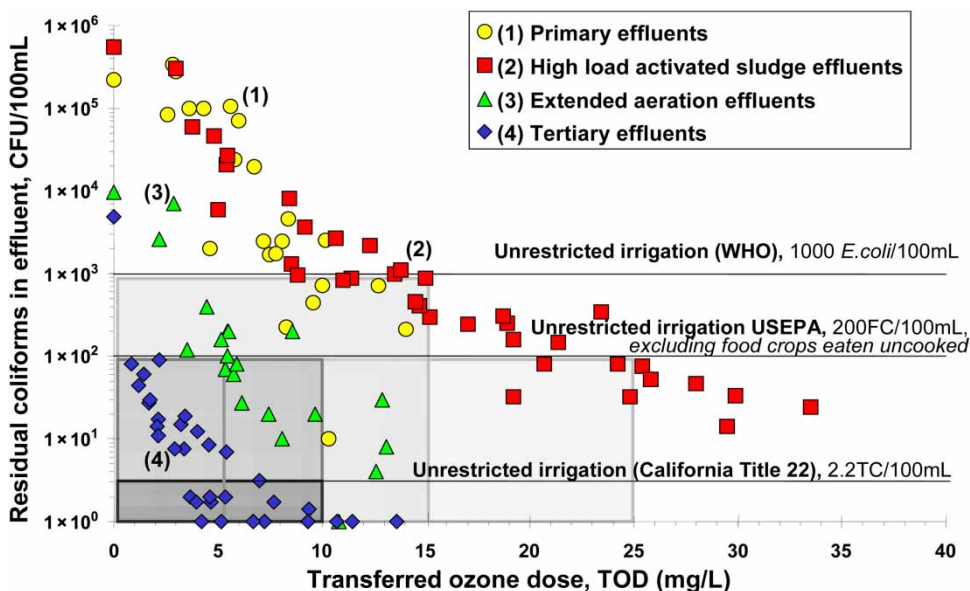


Figure 1 | Performances of ozone for coliform inactivation for different effluents and standards.

necessary to meet the WHO standard for irrigation (1,000 *E. coli*/100 mL). For secondary effluents with poor quality and high total suspended solids (TSS) and COD >100 mg/L (Table 1, pilot 3), more stringent requirements would be difficult to consistently meet even at very high TODs of 25–30 mg/L. To achieve <200 FC or *E. coli*/100 mL, tertiary filtration appears necessary, enabling the achievement of the stringent requirements with a low TOD of 5–10 mg/L.

Similar results were obtained by Liberti et al. (2000) in clarified secondary effluents for the WHO guidelines with a high ozone dose of 15 mg/L and HRT of 10 min. For the same disinfection objective, tertiary filtration enabled the decrease of the ozone dose by 50% to 7 mg/L. The highest disinfection level of 100 TC/100 mL was achieved in tertiary effluent with an ozone dose of 15 mg/L and HRT <5 min. The difficulty in this study of achieving not detectable coliforms could be due to the low filtration efficiency, as the average TSS concentration was 7 mg/L with maximum values up to 10 mg/L. In our experiments, not detectable coliforms were obtained in filtered effluents of very high quality with an average TSS concentration of 2.3 mg/L and maximum values less than 4 mg/L.

The impact of wastewater quality is clearly shown in Figure 2: the TOD required for a 2-log reduction of faecal coliforms varies between 2 and 3 mg/L for tertiary effluents, 6 and 17 mg/L for secondary effluents, and up to between 25 and 30 mg/L for primary effluents. It was observed that with the decrease of effluent quality (increase of TSS, COD), the dispersion of experimental results strongly increases. The

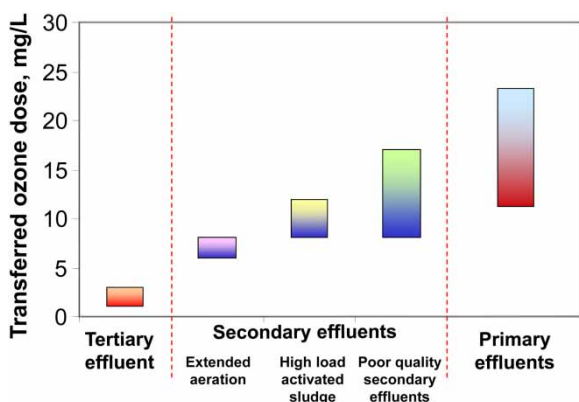


Figure 2 | Range of variations of transferred ozone doses (TODs) required for a 2-log reduction of faecal coliforms in different categories of wastewater.

specific ozone demand calculated on the basis of this investigation is 0.15–0.2 gO₃/COD_{tot}. As a comparison, this value is considerably lower when compared with the specific ozone dose (>0.5 gO₃/gCOD) required for the transformation of persistent COD into biochemical oxygen demand (BOD).

These results clearly demonstrate the need of tertiary filtration not only in order to decrease TOD, but also to consistently achieve stringent regulations, avoiding the shielding impact of suspended solids, which can greatly influence the residual coliform concentration.

The dispersion of the results of disinfection efficiency increases with the decrease of wastewater quality from tertiary, to secondary and primary effluents. For example, for one of the primary effluents tested, the required TOD for a 2-log removal of faecal coliforms was two-fold higher: 16–>20 mg/L compared to the 8–10 mg/L required for secondary effluents. For similar disinfection performance in primary effluents, Absi et al. (1993) reported an ozone dose of 17–20 mg/L. The analysis of TSS and COD concentrations did not provide an explanation for these discrepancies. Other pollutants can also influence disinfections efficiency such as hydrogen sulphide or other chemical compounds consuming ozone with fast kinetics. Similarly to UV disinfection, it was demonstrated that the use of Fe³⁺ as coagulant compared to Al³⁺ could possibly negatively impact ozonation efficiency (excess dissolved Fe²⁺) (Absi et al. 1993).

The influence of water quality on the log-inactivation of faecal coliforms is also observed for secondary effluents with different quality (Figure 3).

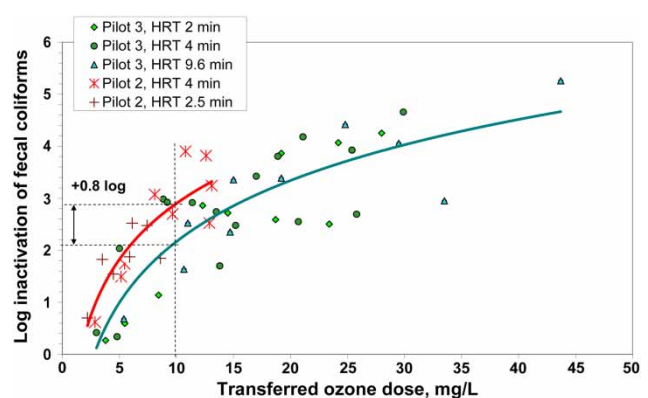


Figure 3 | Influence of TOD and HRT on log removal of faecal coliforms for two secondary effluents.

For a 2-log reduction of faecal coliforms, TOD increased from 6 mg/L in effluents after extended aeration to 10 mg/L for poor quality secondary effluents. To obtain a 3-log reduction, the increase of TOD was from 11 to 17 mg/L. After 4 min retention in the ozonation column and with TODs higher than 8 mg/L, almost total coliform removal was achieved resulting in less than 20 FC/100 mL for high-quality secondary effluents. To achieve total coliform removal in secondary effluents with poor quality (Table 1, pilot 3), very high TODs were needed, over 30 mg/L. This phenomenon can be attributed to the high suspended solid concentration in this effluent, which can shield bacteria from the disinfection agent.

The analysis of the long-term performance of a full-scale ozone facility in France confirms the ability of ozonation to consistently achieve stringent regulations: for a 10-year period, the residual coliform concentrations being consistently less than 100 *E. coli*/100 mL, and this in 98% of the samples for the last two years, despite the variations of flow rate, suspended solids concentrations, TSS (Figure 4(a)) and initial concentrations of *E. coli* (Figure 4(b)). In this full-scale ozonation facility, the variations of TSS in filtered effluent were relatively low with a geometric mean of 1.7 mg/L, median 1.2 mg/L, maximum value of 9.6 mg/L and less than 4 mg/L in 90% of samples. In addition, no *Salmonella* have been detected in any of the analysed samples of disinfected effluents. This high disinfection performance was achieved with low TODs of 2.5–5 mg/L, which is 25–50% of the design ozone dose. On average, a

2.25-log removal of *E. coli* was achieved by ozonation with very low residual concentrations of <100 *E. coli*/100 mL, which is far below the target limit of <1,000 *E. coli*/100 mL.

As shown by Figure 3, another important phenomenon for wastewater ozonation, the hydraulic retention time, does not have a very strong impact on disinfection performances for indicator bacteria, as the FC inactivation remains the same for HRT from 2 to 10 min. Figure 5 confirms this statement, displaying the distribution of ozone residual and FC inactivation along the ozonation column and after 2, 4 and 6 min additional contact in the post-contactor chamber (pilot 3 secondary effluent, TOD 13 mg/L, HRT 4 min). Residual ozone decreased significantly in the post-contactor after 2 min and no significant increase in FC inactivation was observed. The quick decay of ozone may be explained by the wastewater matrix consuming ozone; therefore, no further inactivation can be expected from a post-contactor without additional ozone injection. However, Figure 5 shows clearly the existence of a 'Ct' at the exit of the first column, with a short 'C' half-lifetime between 4 and 6 min, corresponding to rather fast chemical reactions and a long 'C' half-lifetime (similar to what has been measured in potable water disinfection with ozone) resulting in a 'Ct' providing the required disinfection efficiency.

The lower influence of HRT in ozone disinfection of wastewater was demonstrated by other studies in secondary and tertiary effluents (Liberti et al. 2000). In this case, no improvement of disinfection efficiency of coliform bacteria was observed when increasing HRT from 5 to 15 min.

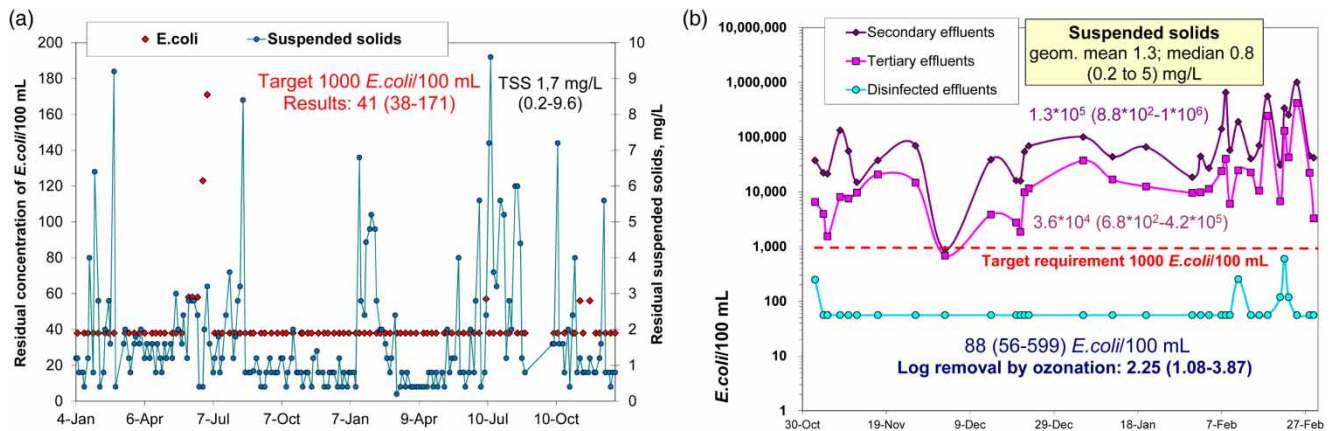


Figure 4 | Influence of suspended solids (a) and initial concentrations of *E. coli* (b) at full-scale (tertiary sand filtration, ozone dose of 2.5–5 mg/L, contact time 20 min, plant capacity 16,500 m³/d).

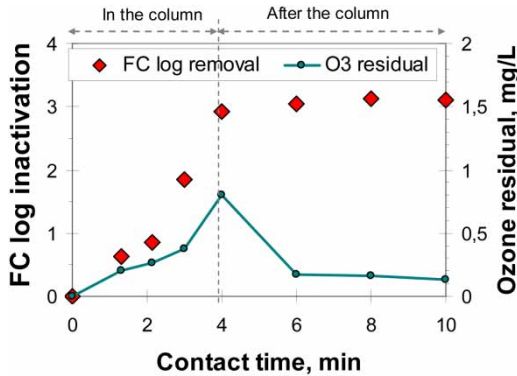


Figure 5 | Influence of contact time of log inactivation of faecal coliforms and the distribution of residual ozone in and after the ozone column.

Influence of operating parameters and indicator microorganism on disinfection efficiency

It is important to stress that within the ozone dose necessary for the inactivation of indicator bacteria as shown previously, a total elimination of enteroviruses was achieved even in the worst quality secondary effluent. The high efficiency of ozone on virus inactivation can be a major advantage of ozone for regulations that include virus removal. In agreement with previous data, bacteriophages were found to be very sensitive to ozone, placing doubt about the pertinence of such microorganisms as indicators for ozone treatment.

By contrast, the higher resistance of *Clostridium* confirms that they are good candidates for a resistant microorganism indicator. Figure 6 illustrates the log inactivation of *Clostridium* in poor quality secondary effluents (pilot 3) for HRT of 2 and 9.6 min. A maximum inactivation of 2.5-log of *Clostridium* was reached for the highest HRT of 9.6 min with a high TOD of 36 mg/L. When bacterial spores and cysts are of concern, hydraulic retention time has a

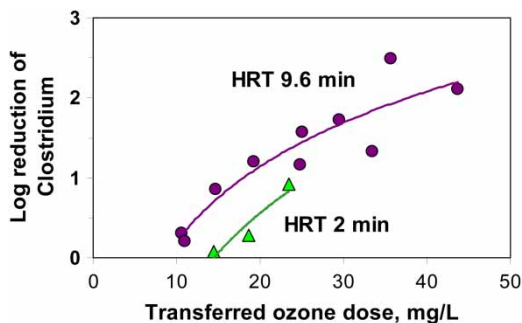


Figure 6 | Influence of TOD and HRT on log removal of *Clostridium* in secondary effluents.

more important impact on ozone disinfection. The essential requirement is, in this case, the establishment of the required 'Ct', which is larger than for the FCs.

A typical set of results of the inactivation of indicator bacteria from the continuous pilot tests conducted on a bubble column are shown in Figure 7. The influence of the COD on the required TOD is well demonstrated.

Similar results (data not shown) were obtained with two pilot plants, one with a bubble column (HRT > 10 min), the other with a short residence time reactor (HRT < 3 min) at a wastewater plant. The performance of the short residence time reactor was the same. In order to provide the necessary homogeneity for the two-phase gas-liquid section (immediate fast reaction zone), as well as for the ozone residual in the post-reaction section (micropollutants' elimination and disinfection) of the whole reactor volume, the short residence time ozonation reactor was designed to operate with a large Re-number (>100,000), with as a consequence, a large Sh-number resulting in a fast mass transfer coefficient k_{1a} and the corresponding turbulent diffusion coefficient ($K_{O_3} > 10^{-5} \text{ m}^2/\text{s}$). Under such turbulent conditions, mass transfer is no longer the factor limiting the overall reaction velocity. In bubble columns with laminar hydrodynamic conditions ($K_{O_3} \approx D_{O_3} \approx 2 \times 10^{-9} \text{ m}^2/\text{s}$), the contrary is true.

Important side effects of ozonation are some lowering of the absorption at 254 nm (Figure 8(a)), indicating a reduction of the size of the molecules, as well as a COD reduction (Figure 8(b)), due mostly to the oxidation of some refractory organics. Interesting, from an ozone system design point of view, is that the specific ozone

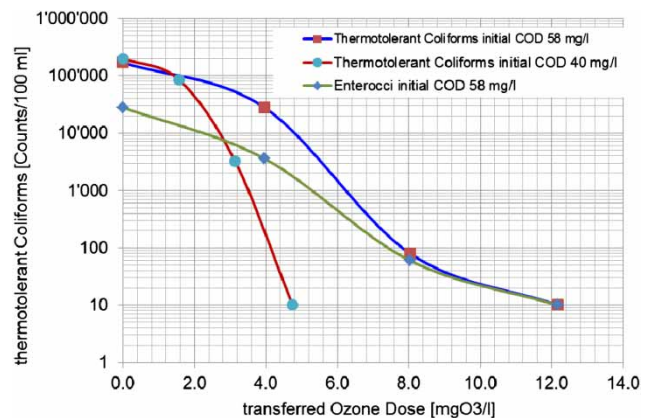


Figure 7 | Influence of TOD on the removal of indicator bacteria in two secondary effluents.

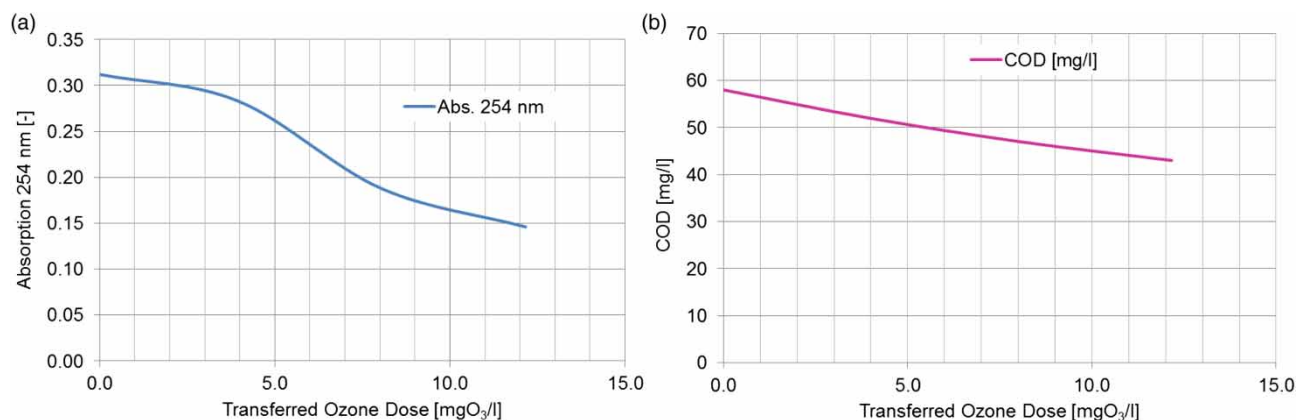


Figure 8 | Performances of ozone for reduction of the 254 nm absorption (a) and COD (b).

consumption by COD abatement is approximately 1 mgO₃/mgO₂. However, this applies only to the given wastewater and is therefore wastewater quality specific since in other pilot tests and full plant measurements, this abatement of COD was much lower for the same TOD.

Similarly to UV absorbance, ozonation also provides a significant reduction of colour, which can be an advantage for some reuse applications. More stringent water reuse regulations like California Title 22 (2000) or USEPA (2012) require the implementation of an efficient tertiary filtration step.

From an operational viewpoint, transfer of ozone from the gas phase to the water was found to be the critical step for faecal coliform inactivation with ozone, because of the fast kinetics between ozone and coliform bacteria. No difference in inactivation was found between 2 and 10 min hydraulic retention time, for a given ozone dose transferred to the effluent.

As a consequence, the 'Ct' approach commonly applied in drinking water treatment should be used for the ozonation of wastewater, with consideration of certain conditions (Tsuno et al. 2008). In the case of short reaction time reactors, the essential condition is the fast homogenisation of the ozone residual.

It is important to stress that short contact times are only possible if fast balanced distribution of the ozone dose introduced into the water or wastewater is achieved as rapidly as possible, in order to satisfy homogeneously the immediate fast chemical reactions (colloidal matter destabilisation, zeta potential, etc.) and enable a uniform distributed ozone residual (or concentration) for the slower reactions, such as disinfection, inactivation of the slower reacting

micropollutants and transformation of hardly biodegradable organics (persistent COD) into BOD. This entails two conditions, as follows.

1. Diffusion: high energy for and density of diffusion (specific power input $>50 \text{ W/m}^3$ and mean velocity gradient $>200 \text{ s}^{-1}$ similar to rapid mixing of coagulant), meaning short residence time, with either fast full mix, or plug-flow co- or counter-current, with a large gas hold-up and a non-negligible head-loss in the diffusion compartment(s). It is imperative to take these two design parameters into consideration for the hydraulic profile of the water or wastewater plant. This high energy for mixing is required because molecular diffusion of ozone ($\approx 2 \times 10^{-9} \text{ m}^2/\text{s}$) is very much slower than the fast chemical reactions ($k_{\text{O}_3} = / > 10^5 \text{ M}^{-1} \text{ s}^{-1}$, according to Hoigné). The physical means to achieve this aim are available, such as the 'free jet', the 'side ejectors', the 'static mixer' and the 'bubble column with porous diffusers', the latter with the appropriate design. For applications in wastewater, as shown by Buffle (2005), a non-negligible amount of ozone is transformed into OH⁻ radicals by the organic matter, which means much faster reactions kinetics, and therefore the need of even faster homogenisation.
2. Reaction: as good as possible plug-flow with a narrow residence time distribution (RTD) for the flow in the reaction compartment(s), with a T10/Th approaching unity as close as possible. This necessarily means a series of vertical compartments, similar to what is being done horizontally for chlorination.

Regarding disinfection control where 'C_{O₃t}' is essential, ozone residual 'C_{O₃}' must be measured in wastewater, but the question is how. Since the half-lifetime of ozone, after the fast reactions have been completed, can amount to several minutes (according to experience up to 10 min and more), an average C_{O₃} can be measured directly with the appropriate instruments (and the necessary maintenance) or indirectly in the off-gas of the diffusion, provided that the residence time of the samples to the instrument is short. This C_{O₃} measurement is of great interest for the operation optimisation of the ozone plants.

Influence of ozonation on chronic toxicity

The influence of ozonation on chronic toxicity was evaluated by means of LuminoTox working with PECs which, when stimulated by light emit fluorescence. As a result of the presence of toxic contamination, the fluorescence emission decreases and this decrease is indicated as per cent inhibition. Unlike the Microtox toxicity test using luminescent bacteria in immunoassays, the LuminoTox is faster, and allows for fast immediate results, almost in real time. As shown in Figure 9, ozonation leads to a reduction of the chronic toxicity.

Nevertheless, these results require careful analysis. There is obviously a decrease of signal response with increased TOD, but in one test an increase takes place again after the dose required for disinfection. This increase could possibly

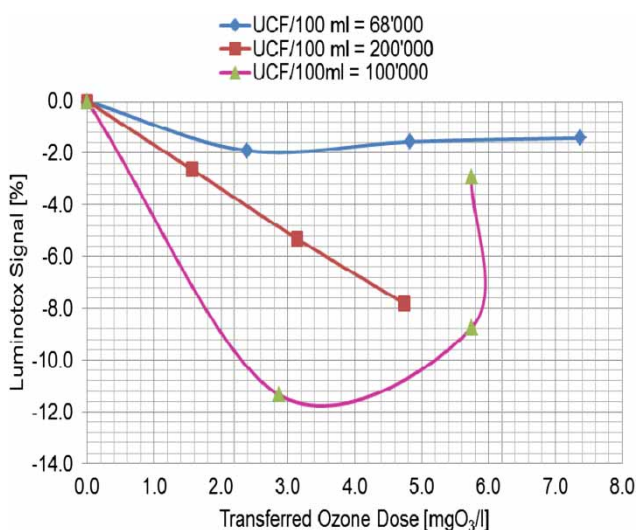


Figure 9 | Performances of ozone for LuminoTox signal reduction.

be explained by the release of micropollutants inhibited in their action while adsorbed on and masked by particles or macro-molecules or by ozonation by-products which could be toxic and resistant to ozonation. Micropollutants can only have an effect when freely soluble in the wastewater, a *sine qua non* for adsorption and absorption by enzymes.

Three complementary studies have been carried out using freshwater mussels and rainbow trout, with the purpose to correlate the results of this new method for chronic toxicity estimation with the LuminoTox signal response. The tests have been performed on untreated and ozone-treated primary and secondary effluents.

The immunotoxic potential of a primary-treated municipal effluent following enhanced disinfection by ozonation was studied in the rainbow trout *Oncorhynchus mykiss* (Hébert et al. 2008) and freshwater mussel *Elliptio complanata* (Gagné et al. 2008). The results demonstrated that ozonation of a primary-treated effluent successfully reduced microbial loading and completely removed the cytotoxicity on mussels. Although effective for disinfection, ozone remains insufficient to eliminate phagocytosis.

CONCLUSIONS

Ozone disinfection appears to be a very efficient process for wastewater disinfection, in particular for water reuse purposes where bacteria and viruses are the target microorganisms. To consistently achieve very stringent standards for unrestricted irrigation, urban uses or indirect potable reuse, preliminary removal of suspended solids by filtration is necessary and highly recommended.

The new approach in the design of ozone contactors for wastewater treatment should be based on short contact times and enhanced mass transfer. Economic considerations also support this approach. Short contact times are only possible if fast balanced distribution of the ozone dose introduced into the water is achieved as rapidly as possible with high energy for mixing with either fast full mix or plug-flow co- or counter-current bubble columns. A non-negligible amount of ozone is transformed into OH⁻ radicals by the organic matter, which means much faster reactions kinetics, and therefore the need of even faster homogenisation. To ensure good reaction, a good plug-flow is also necessary

with, for example, a series of vertical compartments, similar to what is being done horizontally for chlorination. The measurement of ozone residual 'C_{O₃}' is also of great interest for the operation optimisation of the ozone plants.

When piloting in batch, semi-batch or continuous mode, the chemical, hydraulic and hydrodynamic parameters indispensable for the scaling-up from the model (or pilot) to the prototype (or industrial size plant) must be measured and interpreted and the right scaling-up method must be applied with the correct representative dimensionless numbers. The danger with seeking short residence times is that a mistake can easily be made with dramatic consequences. On the other hand, continuous piloting remains expensive, so a programme consisting of well-defined batch tests can be taken into consideration leading to reduced costs.

Any ozonation reactor can be designed with the appropriate hydraulic and hydrodynamic patterns. Basically, it is necessary to have the correct qualitative and quantitative information about the chemical reactions which must be satisfied before an ozone residual starts to build. The 'C_{O₃t}' of most target microorganisms are known.

Another very important property of ozonation is that when a good disinfection is achieved, defined as 100 to 1000 CFU/100 mL, all experimental results available so far confirm that inactivation of viruses and micropollutants is also achieved, based either on direct chemical analysis or with the Lumino-Tox signal response, supported by the Microtox procedure.

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