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Comparison of different advanced disinfection systems for wastewater reclamation

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Abstract Several lines of reclamation have been tested in the Palamós/Vall-Llobrega (Girona, Spain) wastewater treatment plant. Each line consists of a filtration treatment (infiltration–percolation, sand filter, ring filter and physico–chemical treatment) plus a disinfection system (UV, peracetic acid, chlorine dioxide and ozonation). Every combination has been evaluated and compared with the other possibilities. This combination of filtration and disinfection allows the use of lower doses of disinfectants, thus minimising the negative impacts of the whole process and improving the reliability of the reclamation facilities.

Keywords Disinfection; filtration; reclamation; wastewater reuse

Introduction

There are two types of wastewater reclamation treatments: those which, basically, intend to improve secondary wastewater quality, but are not devoted specifically to disinfection, although some of them can improve microbiological quality of wastewater; and specific disinfection systems.

Nevertheless, the majority of wastewater treatment processes can modify water characteristics, removing undesirable particles, transforming organic matter and disinfecting in some proportion. Occasionally, a type of treatment can exert all effects: disinfection, organic matter removal and suspended solids removal, at least. The main problem is usually to define the reclamation line more adapted to specific circumstances.

For this last reason, in Palamós/Vall-Llobrega WWTP (Girona, Spain) a project called DRAC (Desinfección y Reutilización de Aguas Residuales en Cataluña, Wastewater disinfection and reuse in Catalonia) was developed. The project arose from the necessity to define reclamation treatments capable to guarantee an effluent with enough quality to be reused with a minimal microbiological risk.

The DRAC project studies the combination of filtration systems (tertiary treatments) and specific disinfection systems (advanced treatments). The employed technologies are:

- *Intensive technologies:* sand filter (SF), ring filter (RF), ultraviolet (UV), ozone (O_3), peracetic acid (PA), chlorine dioxide (ClO_2) and physical–chemical (PC).
- *An extensive technology:* infiltration–percolation (IP).

The basic aims of this project are:

- to establish the most appropriate technology for wastewater reclamation under a given set of characteristics of a specific site;
- to combine hard and soft technologies and to determine their performances;
- to define the employed equipment capacity to generate tertiary effluent with enough quality for being disinfected, and to disinfect wastewater up to a defined level;
- to quantify the by-products generation.

Material and methods

The Palamós activated sludge facility serves several municipalities in a summer tourist area, with 32,000 inhabitants in winter time and up to 60,000 during the summer season.

The secondary effluent coming from this plant was reclaimed by using different pretreatments before disinfection: infiltration–percolation, ring filter, sand filter and physical–chemical pilot. Those systems were combined with disinfection treatments (with the exception of PC which was tested only in combination with UV and O_3): ultraviolet, ozone, peracetic acid and chlorine dioxide. The main characteristics of the used technologies are as follows:

1. Filtration systems

- *Infiltration–percolation (IP)*. Filtrating surface: 554.7 m^2; depth: 1.50 m of sand (granulometry: 98% below 1 mm), 10 cm of fine gravel, 30 cm of coarse gravel.
- *Ring filter (RF)*. Two modules of filtration: the first has two filters with a filtration degree of 50 μm K 10–15%; the second has three filters with a filtration degree of 25 μm K 10–15%; the maximum flow is 12–13 m^3.
- *Sand filter (SF)*. Classical filter; diameter: 2 m; surface area: 3.14 m^2; depth: 45–50 cm; filtration capacity: 8.12 m^3/h m^2; sand granulometry: 0.6–1.2 mm.
- *Physico–chemical (PC)*. Combination of filtration and coagulation (40 ppm); flow: 7 m^3/h; contact time: 6 minutes.

2. Disinfection systems

- *Chlorine dioxide (ClO_2)*. The pilot has a reactor with a capacity of 1 m^3, a homogenisation tank and a generator of chlorine dioxide.
- *Peracetic acid (PA)*. The pilot has a reactor with a capacity of 1 m^3, a homogenisation tank and a pump that doses the PA.
- *Ultraviolet (UV)*. Closed cylinder; medium pressure and high intensity lamps; 14% of radiation is 253.7 nm.
- *Ozone(O_3)*. Gas source: air; temperature: 0–50°C; pressure: 4–20 mbar.

Physical–chemical and microbiological parameters were determined at the inlet and outlet of the different filtration and disinfection systems. The analytical methods were those indicated by *Standard Methods for the Examination of Water and Wastewater* (1999), except for bacteriophage (ISO), *Giardia lamblia* (EPA) and *Cryptosporidium parvum* (EPA).

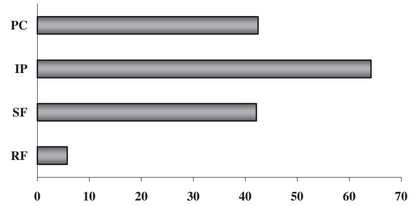
Results

Removal of "contaminants" depends on the filtration system, and obviously the different equipment and lines generated treated wastewater with different qualities. This fact influenced the dose and contact time of studied disinfection systems because "pre-treatments" generated such differences in effluent quality.

Results in relation with filtration systems

Physical–chemical and microbiological parameters variations are presented in Figures 1 to 8. The IP system is the most effective treatment in comparison with the rest of the employed filtration systems (RF, SF, and PC). Outlet water from IP has a removal of suspended solids of 64.19%, COD and TOC are reduced by 31.78 and 56.91%, respectively. On the other hand, BOD_5 is below the detected limit (<5 mg/L). In relation to microbiological parameters, IP improves the microbiological quality. Fecal coliforms are removed in 3.28 Ulog/100 mL, somatic coliphage are reduced in 2.52 Ulog/100 mL, while bacteriophage RNA F-specifics are removed in 1.62 Ulog/100 mL.

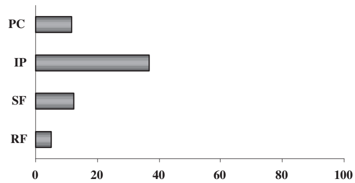
Sand and ring filter remove only suspended solids, and consequently organic matter content is reduced. These filtration systems are not effective for bacteria and virus removal.



	RF	SF	IP	PC
SS	5.74	42.13	64.19	42.44

% removal

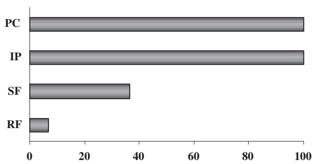
Figure 1 Suspended solids



	RF	SF	IP	PC
COD	5	12.45	36.92	11.74

% removal

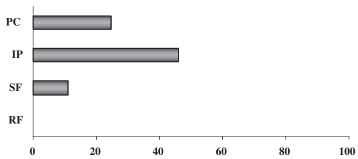
Figure 2 COD



	RF	SF	IP	PC
BOD5	6.91	36.32	100	100

% removal

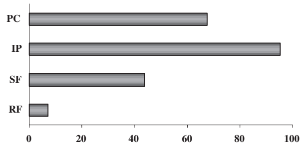
Figure 3 BOD_5



	RF	SF	IP	PC
COT	0	10.97	46.19	24.8

% removal

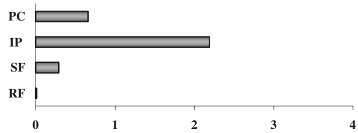
Figure 4 TOC



	RF	SF	IP	PC
Turbidity	7.18	43.85	95.34	67.66

% removal

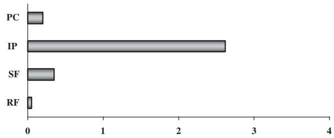
Figure 5 Turbidity



	RF	SF	IP	PC
Fecal coliforms	0.01	0.29	2.19	0.66

removal Ulog/100mL

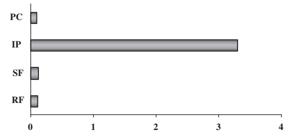
Figure 6 Fecal coliform



	RF	SF	IP	PC
Coliphage	0.05	0.35	2.62	0.2

removal Ulog/100mL

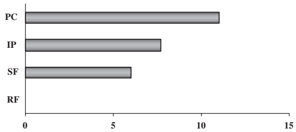
Figure 7 Colifaphage



	RF	SF	IP	PC
Bacteriophage	0.11	0.12	3.3	0.1

removal Ulog/100mL

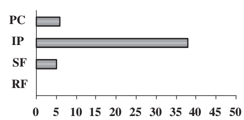
Figure 8 Bacteriophage



	RF	SF	IP	PC
Giardia	0	6	7.67	11

removal cysts/L

Figure 9 *Giardia lamblia*



	RF	SF	IP	PC
Cryptosporidium	0	5	38	6

removal oocysts/L

Figure 10 *Cryptosporidium parvum*

In relation to protozoa removal, SF obtained better results than RF; this fact can be explained due to the granulometry of the SF sand.

The physical–chemical system generates an effluent with better quality characteristics than SF, due to the previous addition of flocculants. The PC system achieves comparable reduction to IP in relation with suspended solids, BOD_5, and turbidity. This system is very effective in protozoa removal, although it has no effect on bacteria and viruses.

Results in relation with treatment lines

Working conditions varied in relation with the origin of the effluent (filtration systems) and are presented in Table 1.

Chlorine dioxide combinations. The applied doses of chlorine dioxide to wastewater generated in the filtration systems allow a total elimination of fecal coliforms in all treatment lines (see Table 2). Somatic coliphages reduction of 3 Ulog was achieved. Bacteriophage RNA *F*-specific were below detection limit ($< 0.1 \times 10^2$ ufp/100 mL) (see Table 2). Chlorine dioxide had the same removal for bacteria and viral indicators (see Table 2).

Table 1 Working conditions in each treatment line

Filtration system	Working Conditions: UV	O_3	PA	ClO_2
SF	Dose: 778.8 mW s/cm^2 Flow: 2 m^3/h	Water flow: 1.2 m^3/h O_2 flow: 202–216 Ln/h Contact time: 2 min. Dose: 19.07–26.32 mg/L Transferred dose: 17.38–25.92 mg/L	Flow: 5.5 m^3/h Contact time: 10 min. Dose: 30 mg/L	Flow: 1.0 m^3/h Contact time: 55 min. Dose: 9 mg/L
RF	Dose: 693.6 mW s/cm^2	Water flow: 1.2 m^3/h Flow: 2 m^3/h O_2 flow: 213–215 Ln/h Contact time: 2 min. Dose: 21.10–27.55 mg/L Transferred dose: 15.54–21.77 mg/L	Flow: 5.5 m^3/h Contact time: 10 min. Dose: 30 mg/L	Flow: 1.0 m^3/h Contact time: 10 min. Dose: 8 mg/L
IP	Dose: 431.9 mW s/cm^2 Flow: 5 m^3/h	Water flow: 1.2 m^3/h O_2 flow: 205–216 Ln/h Contact time: 2 min. Dose: 12.13–12.54 mg/L Transferred dose: 10.45–11.45 mg/L	Flow: 5.5 m^3/h Contact time: 10 min. Dose: 15 mg/L	Flow: 1.0 m^3/h Contact time: 10 min. Dose: 3 mg/L
PC	Dose: 390.8 mW s/cm^2 Flow: 6 m^3/h	Water flow: 1.2 m^3/h O_2 flow: 216–217 Ln/h Contact time: 2 min. Dose: 16.06–16.76 mg/L Transferred dose: 13.42–15.54 mg/L	Further studies	Further studies

n.d = not detected; b.d.l = below detection limit; * = colony forming units

Table 2 Filtration systems combined with ClO_2

Parameter	IP + ClO_2: IP outlet	IP + ClO_2: ClO_2 outlet	RF + ClO_2: RF outlet	RF + ClO_2: ClO_2 outlet	SF + ClO_2: SF outlet	SF + ClO_2: ClO_2 outlet
Fecal coliform (Ulog)	2.39	0.00*	4.84	0.00*	4.24	0.00*
Somatic coliphage (Ulog)	n.d	1.7	3.00	b.d.l.	3.08	b.d.l
Bacteriophage RNA *F*-specific (Ulog)	n.d	b.d.l.	b.d.l.	b.d.l.	n.d	n.d
Giardia (cysts/L)	n.d	<1	72	25	1	<1
Cryptosporidium (oocysts/L)	n.d	<1	5	3	4	3

n.d = not detected; b.d.l = below detection limit; * = colony forming units

Peracetic acid combinations. PA disinfection generated an effluent with approximately 1 Ulog/100 mL of fecal coliforms in the studied lines. Treated water from IP required lower doses than the rest of the filtration systems (for equivalent flow and contact time) (see Table 3). Viral indicators removal varies from 1.7–2.0 Ulog/100 mL. PA as a disinfectant is more effective for bacteria than viruses (see Table 3).

Ultraviolet combinations. UV treatment removes from 2.5–3 Ulog/100 mL of fecal coliform content in all cases, except for RF. UV efficiency depends on suspended solids content and turbidity. The best disinfection results are obtained with the effluents from IP and PC (characterised by their low content in suspended solids and turbidity), where the applied dose was the lowest (see Table 4). The equipment used in this experimentation was characterised by a central lamp, with medium pressure and high intensity. This model is normally used for potable water. and does not adjust to treated wastewater characteristics. Equipment with more lamps is more adequate.

Ozone combinations. Ozone treatment has reduced almost all fecal coliforms of all treated effluents, achieving reductions of 5 Ulog/100 mL (see Table 5). The effluents which needed less ozone concentration were those from the IP and PC pilot; both treatments presenting the lowest organic matter concentration. Organic matter content is extremely related with transmitted ozone dose and consequently influences disinfection efficiency (see Table 5). In relation to viral indicators, a reduction of 5 Ulog/100 mL of somatic coliphages was achieved, while for bacteriophage RNA F-specific the maximum reduction was 3 Ulog/100 mL (see Table 5). Once again, the best removal results were obtained in the effluents which come from IP and PC systems (see Table 5).

Conclusions

A filtration treatment, or equivalent, is usually necessary to eliminate suspended solids before wastewater disinfection. The best filtration system tested in the project was IP. This

Table 3 Filtration systems combined with Peracetic Acid (PA)

Parameter	IP + PA		RF + PA		SF + PA	
	IP outlet	PA outlet	RF outlet	PA outlet	SF outlet	PA outlet
Fecal coliform (Ulog)	2.30	0.09	5.32	0.89	5.02	0.69
Somatic coliphage (Ulog)	n.d	b.d.l	4.80	3.73	4.86	3.74
Bacteriophage RNA *F*-specific (Ulog)	<1	n.d	n.d	n.d	n.d	n.d
Giardia (cysts/L)	n.d	<1	n.d	n.d	n.d	n.d
Cryptosporidium (oocysts/L)	n.d	<1	n.d	n.d	n.d	n.d

n.d = not detected; b.d.l = below detection limit; * = colony forming units

Table 4 Filtration systems combined with Ultraviolet (UV)

Parameter	IP + UV		RF + UV		SF + UV		PC+UV	
	IP outlet	UV outlet	RF inlet	RF outlet	SF outlet	UV outlet	PC outlet	UV outlet
Fecal coliform (Ulog)	4.28	1.74	6.21	6.18	5.51	2.65	4.40	1.44
Somatic coliphage (Ulog)	b.d.l.	b.d.l.	5.12	5.13	6.15	2.54	5.15	1.75
Bacteriophage RNA *F*-specific (Ulog)	b.d.l.	1.70	3.25	3.11	4.18	2.44	3.13	1.30
Giardia (cysts/L)	n.d	<1	3	10	1	2	1	1
Cryptosporidium (oocysts/L)	n.d	<1	14	21	2	6	2	1

n.d = not detected; b.d.l = below detection limit; * = colony forming units

Table 5 Filtration systems combined with Ozone (O_3)

Parameter	$IP + O_3$		$RF + O_3$		$SF + O_3$		$PC + O_3$	
	IP outlet	O_3 outlet	RF outlet	O_3 outlet	SF outlet	O_3 outlet	PC outlet	O_3 outlet
Fecal coliform (Ulog)	4.28	0.27	6.18	0.66	5.63	1.72	4.41	0.87
Somatic coliphage (Ulog)	b.d.l.	1.30	5.13	1.68	6.15	1.45	5.15	b.d.l.
Bacteriophage RNA *F*-specific (Ulog)	b.d.l.	b.d.l.	3.11	2.31	4.18	1.30	3.13	b.d.l.
Giardia (cysts/L)	n.d	<1	10	4	1	1	n.d	n.d
Cryptosporidium (oocysts/L)	n.d	<1	21	25	2	1	n.d	n.d

n.d = not detected; b.d.l = below detection limit; * = colony forming units

system is characterised by an extremely good elimination of suspended solids and micro-organisms retention. Consequently, the effluent needed lower doses and shorter retention time in the advanced disinfection processes, to achieve the same disinfection degree as the rest of the filtration treatments. PC treatment was more effective than SF and RF. Possibly, this fact can be explained by the addition of flocculants, which improve physical–chemical parameters involved in disinfection processes (suspended solids, BOD_5, and turbidity).

In relation to disinfection systems, chlorine dioxide and ozone lines are the most effective, although homogeneous results are not guaranteed with ozone. On the other hand, chlorine dioxide offers more constant results. In all treatment lines has been observed that viruses are more resistant to disinfection than bacteria. The evaluation of this resistance varies in relation with the employed viral indicator.

Further studies are need in relation to *Giardia lamblia* and *Cryptosporidium parvum*.

The chosen treatment is conditioned by other parameters:

- legal requirements;
- treatment reliability;
- technologies available in the country;
- economical viability.

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