Transworld Research Network
37/661 (2), Fort P.O.
Trivandrum-695 023
Kerala, India

Recent Advances in Pharmaceutical Sciences III, 2013: 163-178 ISBN: 978-81-7895-605-3
Editors: Diego Muñoz-Torrero, Amparo Cortés and Eduardo L. Mariño

10. Evaluation of reclamation technologies for wastewater reuse

Laura Alcalde, Montserrat Folch and Josefina C. Tapias
Department of Natural Products, Plant Biology and Soil Science,
Faculty of Pharmacy, University of Barcelona, Av. Joan XXIII s/n, 08028, Barcelona, Spain

Abstract. Reclamation and reuse of wastewater require the use of tools that minimize risks to health and natural ecosystems. There are various types of such tools, among which HACCP (hazard analysis and critical control points) and barrier systems are gaining importance. The research reported here aims to determine and evaluate the most efficient combinations of different treatment systems—barriers—for the reclamation of secondary effluents from urban sewage treatment plants, and for obtaining water of sufficient quality for reuse in accordance with existing legislation, in which water disinfection has become one of the keys to compliance. Several conventional and non-conventional reclamation technologies are evaluated. The results lead us to recommend treatment lines for the different reclaimed water uses established in the Spanish legislation.

Introduction

Reclaimed wastewater can be used to meet part of the demand for water in those areas where the natural supply is insufficient due to the climatology. Reclaimed water resources must be seen in the context of integrated water resource management, mainly as a replacement resource in accordance with

Correspondence/Reprint request: Dr. Laura Alcalde, Department of Natural Products, Plant Biology and Soil Sciences, University of Barcelona, Av. Joan XXIII s/n, 08028, Barcelona, Spain
E-mail: laura.alcalde-sanz@jrc.ec.europa.eu

the quality required for each use. In this regard, it should be noted that such resources are particularly suitable for meeting that part of the demand which does not require water of high sanitary quality [1].

As in other Mediterranean countries, wastewater reuse in Spain is emerging as a viable alternative with an extremely promising future due to the many benefits it presents, such as increased water resources, reduced wastewater discharge into the environment and decreased negative environmental impacts arising from water extraction from the natural environment. However, it also presents some drawbacks, such as risks to health, the need for investment and a reduction in flow rates available in certain sections of a watershed. At present, although the technologies currently available for wastewater reclamation have the capacity to achieve the quality required for reuse in different scenarios, they present several weaknesses, including uncertainly about the reliability of the reclamation processes and about the representativeness of the reclaimed water samples for analysis. Hence, there is a significant need for research, development and innovation aimed at defining and combining treatment systems, and for proactive management of the data obtained [2]. In Spain, the quality required of reclaimed water destined for various uses is established by Royal Decree (RD) 1620/2007 [3]. However, this RD does not constitute a definitive framework for wastewater reclamation and reuse, and has been the catalyst for constant debate about its relevance to the reality of Spain, the errors detected and the economic feasibility of its application, especially as regards the amount of analysis required. The RD is not in line with global trends aimed at overcoming strict adherence of the legislation to reference standards, and thus does not advocate calculations tailored to each situation [4,5,6].

However, even working within the established definition of hazard analysis and risk management, the need for research into the best treatments for wastewater reclamation and reuse still remains. The experimental study presented here formed part of a research project on reclamation and reuse of secondary effluents. The main objective of the project was to evaluate the efficiency of several treatment technologies that were combined in different wastewater reclamation treatment lines aimed at obtaining reclaimed water suitable for reuse in accordance with existing legislation.

1. Reclamation technologies

The study was carried out at a municipal WWTP (wastewater treatment plant) located on the Spanish Mediterranean coast. This plant is an activated sludge facility that has a theoretical flow of 2,400 m^3/day. Part of the secondary effluent was reclaimed by the facility’s existing technologies, which consisted of three pre-treatment systems before disinfection (ring filter, physical-chemical and infiltration-percolation) and three disinfection technologies (chlorine dioxide, peracetic acid and ultraviolet disinfection). All studies were conducted at pilot scale except for infiltration-percolation, and all possible combinations were considered, yielding a total of nine different treatment lines for analysis (Table 1). For the purposes of this study, a treatment line was defined as the combination of a filtration technology (pre-treatment technology) followed by a disinfection technology.

Table 1. Treatment lines evaluated.

Treatment line	Pre-treatment technology	Disinfection technology
1	Ring filter	Chlorine dioxide
2	Ring filter	Peracetic acid
3	Ring filter	Ultraviolet radiation
4	Physico-chemical	Chlorine dioxide
5	Physico-chemical	Peracetic acid
6	Physico-chemical	Ultraviolet radiation
7	Infiltration-percolation	Chlorine dioxide
8	Infiltration-percolation	Peracetic acid
9	Infiltration-percolation	Ultraviolet radiation

1.1. Ring filter

The ring filter (RF) is a filtration system consisting of modules formed by flat plastic rings with slots which are connected in series or in parallel. The extent to which the rings overlap determines a specific light path which in turn determines the particle size retained by the filter [7]. Decompression of the rings to be cleaned occurs in the washing process, and the main mechanism of contaminant removal is mechanical filtration.

The ring filter used was provided by Hidroglobal-Arkal, and consisted of a filtration module in parallel, with a total of four filters (Fig. 1). Each filter body consisted of flat plastic rings with 25 µm slot openings. The feed flow was 9 m^3/h.

Figure 1. View of the ring filter.

1.2. Physico-chemical system

Physical-chemical systems (PC) are based on the addition of coagulants and flocculants to a mixing tank, followed by settling and sand filtration. The main mechanisms of contaminant removal are coagulation-flocculation, sedimentation and mechanical filtration [7]. For the PC system used here, we employed an inorganic coagulant (poly aluminum PAX18), followed by lamellar settling and, at the end of the process, two sand filters for mechanical filtration. The feed flow was 8m^3/h, and the pilot plant and necessary reagents were provided by Kemira (Fig. 2).

Figure 2. View of the physico-chemical system.

1.3. Infiltration-percolation

Infiltration-percolation (IP) is a non-conventional or extensive technology that can be defined as an aerobic treatment process with a fixed biomass (biofilm) in unsaturated fine granular media (sand) which uses sequential feeding with a discontinuous input of organic matter, nutrients and oxygen, infiltrating wastewater in a controlled manner [8,9]. Infiltration-percolation uses a filter bed to which a biofilm is attached. The filter bed consists of sand with a particle size calibrated to achieve filter uniformity. The granulometry of the sand ensures rapid renewal of the gas phase, and permits retention of suspended solids and control of the percolation rate in relation to oxidation and disinfection kinetics. Grass is always present on the surface of the system in order to avoid preferential hydraulic flow paths.

IP systems are mainly based on the presence of a biofilm, which implies a carrier material (grains of sand) and organisms capable of forming a biofilm. The biofilm is mainly composed of bacteria, although other organisms such as protozoa and metazoa are present. These organisms form complex aggregates with extracellular polymers and metabolic compounds and minerals. Infiltration-percolation systems act to remove wastewater contaminants basically through mechanical filtration and biological oxidation [9]. The IP system used here was especially constructed for this project (Fig. 3) and consisted of a 1.50 m deep sand filter bed (98% particle size <1 mm in diameter, d10 0.28 mm, with a uniformity coefficient of 3.61) which provided a functional surface of 144.67 m^2 and had a nominal hydraulic loading capacity of 0.69 m/day. The feed flow was 6 m^3/h. Wastewater was fed into the system through evenly distributed subsurface drip irrigation lines.

Figure 3. View of the infiltration-percolation system.

1.4. Chlorine dioxide

Chlorine dioxide (ClO_2) is an effective oxidant used for phenol contaminated waters and for eliminating odor problems while disinfecting. This disinfectant does not react with ammonia or with bromine, and does not generate noticeable amounts of byproducts, although oxidized compounds and ions such as iron, manganese, and nitrates may be generated [7]. Due to its instability, chlorine dioxide must be generated in situ. The pilot plant used in this project consisted of a Bellozon CDVa35 chlorine dioxide generator (ProMinent Gugal, SA), a homogenization tank of 1 m^3 and a shaker (Fig. 4).

The feed flow was of $1m^3/h$, with a peak production of ClO_2 of 46 g/h. The chlorine dioxide production method consisted of mixing a sodium chloride solution with a hydrochloric acid solution, according to the following reaction:

$$5NaClO_2 + 4HCl \rightarrow 4ClO_2 + 5NaCl + 2H_2O$$

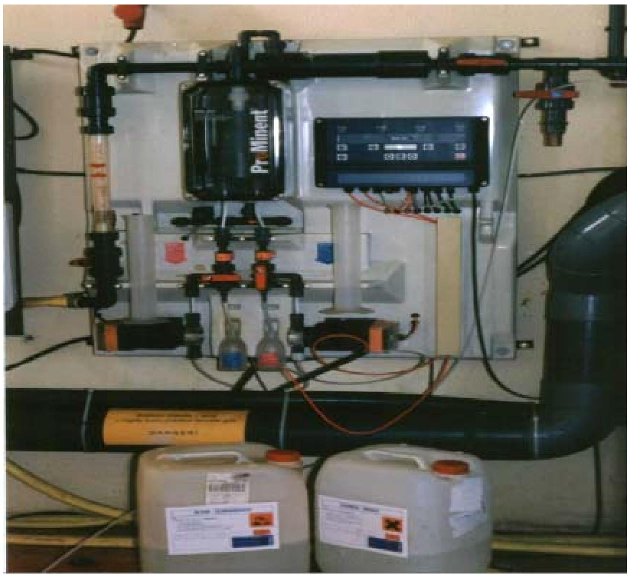

Figure 4. View of the chlorine dioxide generator.

1.5. Peracetic acid

Peracetic acid (PA) is a powerful oxidant and its disinfectant action is due to the damage caused at the lipoprotein membrane of the microorganisms, modifying the conveying action of the proteins leading to lysis [7]. Peracetic acid is chemically unstable and is produced from the reaction between hydrogen peroxide and acetic acid, according to the following reaction:

$$CH_3\text{-}COOH + H_2O_2 \rightarrow CH_3\text{-}COOOH + H_2O$$

The peracetic acid system used consisted of a stirred reactor which was fed with the wastewater to be treated and peracetic acid, which was dosed by a pump (ProMinent Gugal, SA.) (Fig. 5) fitted with a pressure valve to prevent fluctuations. The feed flow was $1m^3/h$.

Figure 5. View of the peracetic acid system.

1.6. Ultraviolet radiation

The ultraviolet radiation (UV) system is a physical disinfection technology that acts on the nucleic acids and proteins of the microorganisms, deactivating them [7]. Normally, monochromatic radiation of 253.7 nm is used because it is considered the most effective wavelength as a germicide, although the possibility of bacterial reviviscence must be taken into account. The UV system used (UV3000PTP) was provided by Trojan (Fig. 6). The system had six low pressure lamps, was 1,626 mm long and was used with a feed flow of 5 m^3/h.

Figure 6. View of the peracetic acid system.

2. Evaluation of reclamation technology’s efficiency

The doses and contact times of the disinfectants were established in preliminary tests, and varied according to the filtration process to which the secondary effluent was subjected, as indicated in Table 2.

The chemical parameters analyzed [10] included some of the parameters required by Spanish legislation, in addition to other parameters that permit a better assessment of disinfection effectiveness. The microbiological parameters analyzed consisted of two bacterial indicators, E. coli and total coliforms [10], and a virus indicator, somatic bacteriophages [11]. E. coli was selected as the bacterial indicator because it is used in Spanish and international reuse legislation. Total coliforms are used in more restrictive regulations, such as the legislation in the State of California, but there is a worldwide trend to stop using them because their origin is not only fecal and they can be found in natural environments. Each treatment line was evaluated independently for one year.

The secondary effluent was characterized by physical-chemical and microbiological parameters (Table 3).

According to the obtained results, the secondary effluent was very heterogeneous with large deviations, especially as regards COD, SS, and turbidity, parameters that are known to affect the performance of disinfection technologies. Also notable was the variation in dissolved oxygen content, which can affect the performance of infiltration-percolation systems.

The results obtained during evaluation of the outlet effluent from the pretreatment technologies are shown in Figure 7. There was a certain degree of variability in COD, suspended solids and turbidity at the outlet of the different pretreatment systems. According to the results, the pretreatment systems achieved homogenization of effluent quality and had the capacity to cope with peak loads of contaminants caused by problems in the biological treatment and the final secondary decantation at the WWTP.

Table 2. Doses and contact times of the disinfectants.

	Chlorine dioxide	**Peracetic acid**	**Ultraviolet radiation**
Ring filter	8 mg/L T: 40 min	9.5 mg/L T: 11 min	59 mW·s/cm^2
Physico-chemical	5 mg/L T: 85 min	8.5 mg/L T: 11 min	94 mW·s/cm^2
Infiltration-percolation	5 mg/L T: 55 min	8.5 mg/L T: 11 min	97 mW·s/cm^2

T: contact time

Table 3. Characterization of the secondary effluent.

Parameter	Min.	Av.	Max.	St. Dev.
pH	7.8	8.4	9.4	0.5
Temperature ºC	15.5	21.5	27.9	3.5
Electrical conductivity (µS/cm)	1221	2076	2884	260
Dissolved oxygen (mg/L)	0.14	2.61	6.7	1.31
COD (mg/L)	17.0	69.9	242	46.2
Suspended solids (SS) (mg/L)	5.5	95.9	572	127.8
Turbidity (NTU)	3.0	42.8	267	54.5
Ca soluble (mg/L)	96.7	128.4	145.8	15.7
Mg soluble (mg/L)	24.6	33.7	38.2	4.3
Na soluble (mg/L)	169.0	246.2	304.7	46.8
K soluble (mg/L)	14.1	16.0	17.7	1.1
N-TKN soluble (mg/L)	4.3	8.8	13.9	3.7
N-NH_4^+ (mg/L)	<0.25	0.9	5.33	1.6
P soluble (mg/L)	<0.50	1.2	2.79	0.80
E. coli (Log cfu/100mL)	4.5	5	5.4	0.3
Total coliforms (Log cfu/100mL)	5.4	5.9	6.4	0.3
Somatic bacteriophages (Log pfu/100mL)	1.8	2.6	3.3	0.5

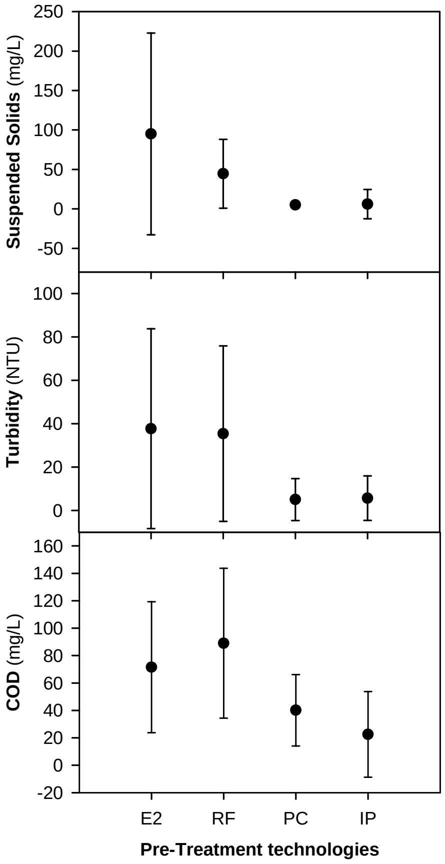

Figure 7. Average concentration and standard deviation of physicochemical parameters in the secondary effluent and the outlet effluent of each pre-treatment system.

The best removal rates of COD, SS, and turbidity are obtained by the infiltration-percolation system; this result can be explained based on its granulometric characteristics. (98% of particles are <1 mm in diameter) that determine the efficiency of the retention of suspended solids in the surface, and colloidal and dissolved solids in in the deepest area of the sand filter bed. It is to note that the sand filter depth (1.50 m) lengthens the filtration time, which should result in a better contaminant removal rate [12]. A substantial part of the organic matter is degraded by aerobic microorganisms which are part of the filter bed associated biofilm [13]. The efficiency of this infiltration-percolation system is comparable to the ones of infiltration-percolation systems with surface irrigation [14].

With respect to the physical-chemical system, SS reductions were very similar to those obtained with the infiltration-percolation system. The addition of chemicals in the physical-chemical system resulted in the aggregation of colloidal particles to form flocs that were subsequently decanted [15]. The lowest removal rates were obtained with the ring filter system, because only particles larger than the pore size of 25 µm were removed from the effluent. However, it should be noted that despite these apparently poor results, the ring filter system met the design specifications and would thus be completely efficient and adequate for less restricted wastewater uses. The reduction obtained in turbidity could be explained in the same way as the reduction in suspended solids, since both parameters are usually related.

The average concentrations and standard deviations for E. coli, total coliforms and somatic bacteriophages in the secondary effluent (inlet of each pretreatment system) and outlet effluent of the pretreatment technologies are presented in Figure 8. With regard to the mechanisms associated with the reduction in microorganisms yielded by the different technologies used, it should be borne in mind that some microorganisms were associated with solid particles and were therefore retained by the filtering mechanisms [15,16]. The infiltration-percolation system gave the highest removal rate, with an average E. coli reduction of 2.2 log cfu/100 mL. The physical-chemical and ring filter systems produced similar average reductions of 0.3 log cfu/100 mL, although the physical-chemical system achieved a slightly higher removal in some cases.

The removal of total coliforms was very similar to that observed for E. coli. The results show that the content of total coliforms was generally 2 log units higher than E. coli content, indicating that an important percentage of total coliforms was environmental rather than fecal in origin.

The mechanisms of disinfection in the infiltration-percolation system are associated with filtration, adsorption and predation. Filtration and adsorption are based on physical processes that achieve immobilization of pathogens

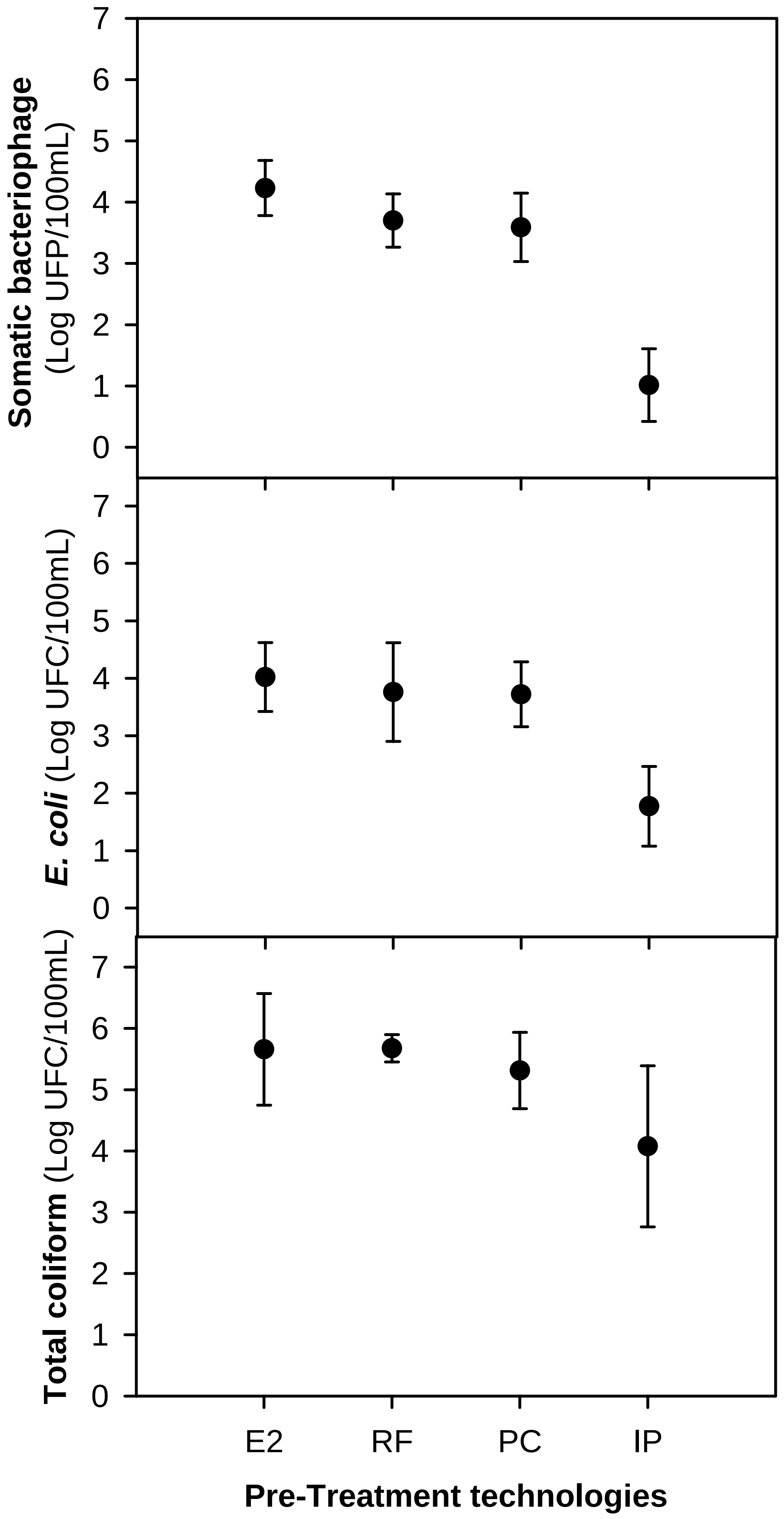

Figure 8. Average concentration and standard deviation of microbiological parameters in the secondary effluent and the outlet effluent of each pre-treatment system.

that are either associated with particles or free, while predation is a biological mechanism of competition typical of systems using biomass [17]. The system's hydraulic retention time plays a key role in the reduction of microorganisms.

The physical-chemical system reduced the concentration of bacteria because the microorganisms were trapped in the flocs formed once the chemical reagent had been added [18].

The infiltration-percolation system achieved the highest removal of somatic bacteriophages, with an average reduction of 3.2 log pfu/100mL, followed by the physical-chemical system (0.6 log pfu/100mL) and the ring filter system (0.5 log pfu/100mL). The virus removal mechanisms of each system were the same as those described for bacteria, although in some circumstances (heavy rains) bacteriophages could be desorbed [19, 20, 21].

2.1. Evaluation of the final reclaimed effluents quality

The results for microbiological water quality at the end of the treatment lines, following application of the disinfection technologies at the doses and contact times previously described, are shown in Table 4.

The treatment lines which achieved the highest removal of indicator microorganisms were those that used physical-chemical (PC) and infiltration percolation (IP) systems as pretreatments. The lowest removal rates were obtained for the RF+UV treatment line. This was an expected result, given that the high concentration of suspended solids due to the poor removal achieved by the ring filter interfered with the disinfectant action of the ultraviolet radiation, reducing its effectiveness [22, 23]. There were no significant differences between the disinfection efficiency of chlorine dioxide and peracetic acid, the most effective disinfectants evaluated, and the results are in agreement with other studies using similar doses and contact times [24,25].

According to the limits established by RD 1620/2007 for E. coli content in final effluents, the reclaimed water from the treatment lines employing physical-chemical and infiltration-percolation systems could be used for the urban, agricultural, industrial and recreational uses established in the Spanish legislation. The lines that used the ring filter system also met the requirements for the above-mentioned uses, except for urban uses, the most restrictive ones.

Table 4. Content and removal of microorganisms at the end of the treatment lines evaluated.

Treatment line	***E. coli* (log cfu/100mL)**		**Total coliforms (log cfu/100mL)**		**Somatic bacteriophages (log pfu/100mL)**	
	Conc.	**Rem.**	**Conc.**	**Rem.**	**Conc.**	**Rem.**
RF+ClO_2	0.2	4.8	1.3	4.6	0.2	2.4
RF+PA	1.0	4.0	2.5	3.4	0.5	2.1
RF+UV	2.3	2.7	2.5	3.8	0.3	2.3
PC+ClO_2	0.4	4.6	1.2	4.7	0.0	2.6
PC+PA	0.3	4.7	1.2	4.7	0.3	2.3
PC+UV	0.9	4.1	1.9	4.0	0.0*	2.6
IP+ClO_2	0.4	4.6	1.1	4.8	0.0*	2.6
IP+PA	0.2	4.8	1.2	4.7	0.0*	2.6
IP+UV	0.6	4.4	0.5	5.4	0.0*	2.6

*: below detection limit (1 pfu/100mL); Conc.: final concentration; Rem: final removal.

3. Conclusion

The infiltration-percolation and physical-chemical pretreatment systems evaluated in this study showed consistent performance, being capable of homogenizing effluent quality during peak loads. Furthermore, infiltration-percolation is a "green" technology that is environmentally friendly since it does not require chemical additives for operation.

As regards wastewater disinfection, the chlorine dioxide and peracetic acid disinfection systems proved to be the most effective at the doses and contact times tested. The efficiency of ultraviolet radiation as a disinfectant was influenced by the presence of suspended solids which, as expected, decreased its effectiveness.

However, determination of the costs involved in the treatment line selected for a reclamation facility can be an important factor, and the ring filter may be more cost efficient for certain uses.

4. Future perspectives of the wastewater reclamation and reuse

Wastewater reuse remains the subject of research, and some of the leading researchers in the field continue to assess the hazards and health risks associated with wastewater reuse [26,27].

Drinking Water Safety Plans [28] have been implemented worldwide over the last three years, but nothing has been done in relation to the treatment, reclamation, distribution and reuse of wastewaters [29]. There is thus a need to design research methodologies and tools capable of generating the data and results necessary for correct evaluation and use of reclaimed water with an acceptable risk, as established in the published recommendations.

The objectives to be achieved in the coming years, given the difficulties in adapting the Spanish RD 1620/2007 for wastewater reuse, include:

Implementation of the Hazard Analysis and Critical Control Points (HACCP) protocols, including determination of CCPs (Critical Control Points), calculation of DALYs (Disability Adjusted Life Years), calculation of QMRA (Quantitative Microbial Risk Assessment) and QCRA (Quantitative Chemical Risk Assessment), determination of acceptable risk, identification of risk reduction methods (using barriers, better technologies, etc.) and validation of methodologies.
Management of storage, distribution and application of reuse systems.
Monitoring of the environmental matrices receiving reclaimed water directly or indirectly (including protected areas).

Acknowledgements

This project received financial support from the Entitat of Sanejament d'Aigues residuals (EPSAR, Government of Valencia) and the SOSTAQUA project (CENIT Program), led by Aguas de Barcelona, and was subsidized by the CDTI (Industrial and Technological Development Center, Government of Spain) through the Ingenio 2010 Program. The staff at the WWTP of Bétera (Valencia) collaborated in sample collection and analytical determinations. Kemira, Trojan, and Hidroglobal-Arkal supplied some of the reagents and technologies.

References

1. Toze, S. 2006, *Agric. Water. Manage.* 80, 147-159.
2. Salgot M; Folch M. 2010, *La reutilización del agua en la Región Mediterránea: realidad y perspectivas.* Reutilización de aguas regeneradas: Aspectos tecnológicos y jurídicos. Fundación Instituto Euromediterráneo del Agua.
3. RD 1620/2007 *Régimen jurídico de la reutilización de las aguas depuradas* BOE num. 294, December 8th, Ministry of the Presidence, Spanish Government.
4. World Health Organization, 2005, Water Safety Plans *Managing drinking-water quality from catchment to consumer* Water. Sanitation and Health Protection and the Human Environment, Geneva.
5. Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, Australian Health Ministers' Conference 2008 Australian guidelines for water recycling: managing health and environmental risks: Phase 2. Augmentation of water drinking supply. National Water Quality Management Strategy. Canberra, Australia.

6. Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, Australian Health Ministers' Conference 2009, Australian guidelines for water recycling: managing health and environmental risks: Phase 2c: Managed aquifer recharge. National Water Quality Management Strategy, Canberra, Australia.
7. Tchobanoglous, G., Burton, F.L., Stensen, H.D. 2003, Wastewater engineering, treatment and reuse. Metcalf & Eddy Inc., McGraw- Hilll, New York, USA.
8. Folch, M. 1997, Tratamiento terciario de aguas residuales por infiltración-percolación: parámetros de control. PhD thesis. University of Barcelona.
9. Auset, M. 2002, Approche des mécanismes de décontamination en infiltration-percolation. PhD thesis. Université Montpellier II.
10. American Public Health Association, 2005, Standard Methods for the examination of Water and Wastewater. 21st ed., Washington D.C.
11. International Organization for Standardization, 2000, Water quality-detection and enumeration of bacteriophages. Part 2: Enumeration of somatic coliphages. ISO 10705-2, Geneva.
12. Folch, M., Huertas, E., Tapias, J.C., Salgot, M. and Brissaud, F. 2003, *Water Sci. Technol: Water Supply*. 3 (3). 161-165.
13. Brissaud. F.; Salgot. M.; Folch. M.; Auset. M.; Huertas. E. y Torrens. A. 2007, *Water Sci. Technol*. 55(7), 227 234.
14. Alcalde, L., Folch, M., Tapias, J.C., Huertas, E., Torrens, A. and Salgot, M. 2007, Wastewater reclamation systems in small communities. *Water Sci. Technol*. 55(7). 149-154.
15. Rajala, R.L., Pulkkanen, M., Pessi, M., Heinonen-Tanski, H. 2003, *Water Sci. Technol*. 47 (3), 157-162.
16. Petala, M., Tsiridisa, V., Samaras, P., Zouboulis, A., Sakellaropoulos, G.P. 2006, *Desalination* 195, 109-118.
17. Brissaud, F., Salgot, M., Bancolé, A., Campos, C., Folch, M. 1999, *Water Sci. Technol*. 40 (4-5), 215-222.
18. Gómez-López, M.D., Bayob, J., García-Cascales, M.S., Angosto, J.M. 2009, *J. Clean. Prod.* 17, 1504-1511.
19. Lucena, F., Duran, A.E., Morón, A., Calderon, E., Campos, C., Gantzer, C., Skraber, S. 2004 *J. Appl. Microbiol.* 97, 1069-1076.
20. Méndez, J., Audicana, A., Isern, A., Llaneza, J., Moreno, B., Tarancon, M.L., Jofre, J., Lucena, F. 2004, Standardised evaluation of the performance of a simple membrane filtration-elution method to concentrate bacteriophages from drinking water. J. Virol. Methods 117, 19-25.
21. Costán-Longares, A., Montemayor, M., Payán, A., Méndez, J., Jofre, J., Mujeriego, R., Lucena, F. 2008, *Water Res*. 42 (17), 4439-4448.
22. Caretti, C., Lubello, C. 2003, *Water Res*. 37 (10), 2365-2371.
23. Hijnen, W.A.M., Beerendonk, E.F., Medema, G.J. 2006, *Water Res*. 40 (1), 3-22.
24. Koivunen, J., Heinonen-Tanski, H. 2005, *Water Res*. 39 (18), 4445-4453.
25. Koivunen, J., Heinonen-Tanski, H. 2005, *Water Res*. 39 (8), 1519-1526.
26. Karavarsamis, N., Hamilton, A.J. 2010, *J. Water Health* 8 (2), 365-373.
27. Donald, M., Mengersen, K., Toze, S., Sidhu, J.P., Cook, A. 2011, *J. Water Health* 9 (1), 10-26.

28. Bartram, J., Corrales, L., Davison, A., Deere, D., Drury, D., Gordon, B., Howard, G., Rinehold, A., Stevens, M. 2009, Water safety plan manual: step-by-step risk management for drinking water suppliers. World Health Organization, Geneva.
29. Ayuso-Gabella, N., Page, D., Masciopinto, C., Aharoni, A., Salgot, M., Wintgens, T. 2011, *Agric. Water Manag*. 99(1), 93-102.