Wastewater infiltration percolation for water reuse and receiving body protection: thirteen years' experience in Spain

Water Science & Technology **Vol 55 No 7 pp 227–234** © IWA Publishing 2007

F. Brissaud*, M. Salgot, M. Folch**, M. Auset***, E. Huertas** and A. Torrens****

*Hydrosciences, MSE, Université Montpellier II, 34095 Montpellier Cedex 05, France
(E-mail: *brissaud@msem.univ-montp2.fr*)

**Institut de l'Aigua de la Universitat de Barcelona. Facultat de Farmàcia. Joan XXIII, s/n. 08028 Barcelona, Spain (E-mail: *salgot@ub.edu*; *mfolch@ub.edu*; *ehuertas@ub.edu*; *antoninatorrens@ub.edu*)

***Bren School of Environmental Science and Management, University of California, 2323 Bren Hall, Santa Barbara, CA 93106, USA (E-mail: *mauset@bren.ucsb.edu*)

Abstract Infiltration percolation (IP) is an extensive technology to treat primary or secondary effluents of small and middle size communities before reuse or disposal to sensitive receiving bodies. Thirteen years of implementation of IP in Spain has highlighted the necessity to abide by defined design and construction rules and operation conditions in order to achieve consistently the treatment objectives and guarantee a long lasting treatment capacity. From this experience, high care should be taken of (i) the characteristics of the sand constituting the filter, (ii) the drainage conditions, (iii) the influent spreading over the infiltration surface and (iv) the risks related to recurrent overloading. Simple monitoring measures are suggested in order to improve the reliability of IP plants.

Keywords Clogging; infiltration percolation; overloading, porous medium; wastewater

Introduction

Infiltration percolation (IP) is an extensive treatment technology which consists essentially of intermittently infiltrating wastewater through 1.5–2.0 m deep unsaturated sand beds (Figure 1). As the mean hydraulic load can not exceed about $0.65\,m^3\,d^{-1}$ per m^2 of sand bed, the capacity of these IP systems usually does not exceed a few thousand p.e., but may reach higher values, up to 25,000 p.e. when treating secondary effluents. Larger plants would require too much filter surface and sand volume.

More than 10 infiltration percolation plants (IPP) have been constructed in Spain to treat secondary effluents prior to water reuse or disposal in nearby river beds (Table 1). The Vall-Llobrega (Girona province) IPP has been in operation since 1992; the treated water is being used for irrigation of poplars. A second plant was recently added to Sant Lluís I (Balearic Islands) IPP, in order to face the increasing demand for reclaimed water used for alfalfa irrigation and hotel dual systems. Water treated through the two filters of Torrevieja (Alicante province) is used for urban landscape irrigation and supplying ornamental impoundments. The effluent of Piera (Barcelona province) IPP is used for market gardening irrigation. Water from Els Hostalets de Pierola (Barcelona Province) will be used for agriculture as soon as permission is acknowledged by the authorities. Elda (Alicante province) IP effluent is to be directed to the agricultural water supply system, although the plant was commissioned several years ago. IPP effluents of El Biar, El Rincón de la Bonanza in Alicante province, Ojos de Garza in Canary Islands and Els Hostalets are disposed of in usually dry stream beds.

doi: 10.2166/wst.2007.149

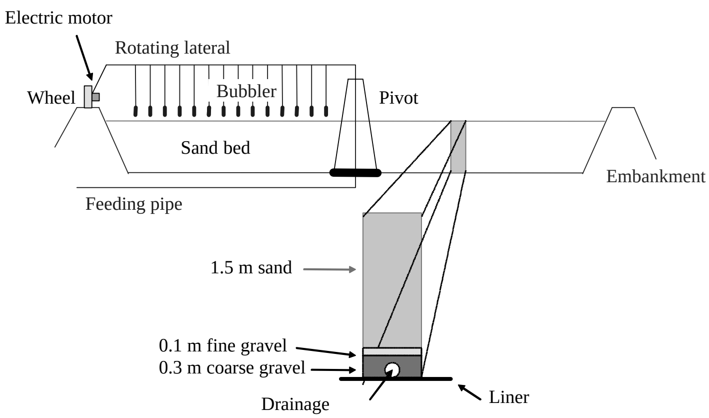

Figure 1 Typical layout of infiltration percolation systems built in Spain

This low energy consumption technology has proven to be an efficient means of reclaiming primary or secondary effluents, thus allowing water reuse and protecting sensitive receiving water bodies (Bouwer, 1996; Makni, 2001). Indeed, full size plant monitoring showed that helminth eggs are retained through pore straining in the upper layer of the filtrating beds and are totally removed (Guessab *et al.*, 1993); protozoa such as *Giardia lamblia* and *Cryptosporiidum parvum* were not detected in the filtered water of Vall Llobrega IPP by Alcalde *et al.* (2006); *Escherichia coli* content can reliably reach the less than 1000 cfu/100 mL target (Salgot *et al.*, 1996; Brissaud *et al.*, 1997; Castillo *et al.*, 2001) and monitoring performance of Piera and Vall-Llobrega IPPs exhibited several log units removal of somatic coliphages and bacteriophages RNA-F specific (Brissaud *et al.*, 1997; Alcalde *et al.*, 2006).

Laboratory investigations and field data have shown that, though IPPs are low technology systems, achieving both the designed performance, i.e. final effluent completely oxidized and efficiently disinfected, and long-lasting treatment capacity requires abiding by well defined design and construction rules and operation conditions. More than 13 years' implementation of IP systems in Spain and Mediterranean countries has brought some light on the necessity to keep to these requirements. This paper presents lessons learned from this experience.

Porous medium

The choice of the sand that will constitute the filter is a crucial step in IPP construction planning. Too high permeability due to too coarse sand would result in high percolation

Table 1 Infiltration percolation plants in Spain

Plant	Starting operation year	Useful bed surface (m^2)	Applied effluent	Capacity (m^3/day)
Vall-Llobrega	1992	575	Secondary	300
Piera	1996	428	Secondary	220
Sant Lluís I	1994	1254	Secondary	630
Sant Lluís II	2003	4955	Secondary	2300
Torrevieja I	1998	1455	Secondary	730
Torrevieja II	2002	2139	Secondary	1100
Elda	1998	4712	Secondary	2400
Els Hostalets de Pierola	1998	875	Primary	250
El Biar	1999	180	Secondary	90
El Rincón de la Bonanza	1999	1400	Secondary	700
Ojos de Garza	2001	370	Secondary	200

water velocities and, owing to oxidation and disinfection kinetics, lead to low oxidation of the treated water – unless the water is re-circulated as in trickle filters or gravel filters (Ménoret *et al.*, 2002) – and poor disinfection. On the other hand, low sand permeability together with biofilm development would reduce infiltration capacity, impede the renewal of the air phase and prevent oxygen supply, leading to anaerobic conditions which are incompatible with IP proper functioning and performance. The recommended mean grain size ranges between 200 and 800 μm with a uniformity coefficient, d_{60}/d_{10}, being less than 10. Sand may be supplied from dunes, alluvial material or quarries after crushing and sieving. Its characteristics should be closely monitored during the whole construction period.

IP is an aerobic fixed biomass process. Its treatment performances and durability rely on balanced oxygen supply and demand. Oxygen is supplied to the filter by convective and diffusive exchanges with the atmospheric air through the bed surface. Therefore, maintaining the sand bed unsaturated and the infiltration surface free of water during the main part of the operation time is crucial. Porous medium defects affect negatively the process.

Poor (or absence of) washing before supplying the sand to the construction site always results in an important deterioration of filter performance. As was observed in Torrevieja II IPP, even low fine particles content leads, when these fines are mainly clay, to a severe reduction of the treatment capabilities. The sand constituting this filter was not fully washed before the bed was laid on. Though the fraction of particles less than 20 μm did not exceed 1%, fines were put in suspension during the feeding sequences, then settled gently in the furrows modelled by the bubbler sprays on the infiltration surface, inhibiting dramatically the permeability of the upper layer of the filter, thus undermining both infiltration and oxidation capabilities (Figure 2).

Clay or silt can also enter the systems during the construction of the facilities, due to bad sand manipulation and earth contamination. When the filter starts operating, the infiltrating water flushes down the small particles, clay and silt, which migrate downward and accumulate locally and at variable depth within the sand beds, as was also observed in Torrevieja. The same process may occur when, due to operation and management deficiencies or recurrent overloading, the treatment capacity of an IP filter has been too much reduced. Indeed, the first retrofitting measure envisaged by the operator or the facility owner is often the replacement of the upper sand layers by clean new sand, as happened at Vall-Llobrega and Sant Lluís. Then, if this new sand has not been carefully chosen, it may happen that fine particles contained in the new sand are washed down to the interface between the new and the old sands, creating a low permeability layer. This phenomenon was described by Auset (2002).

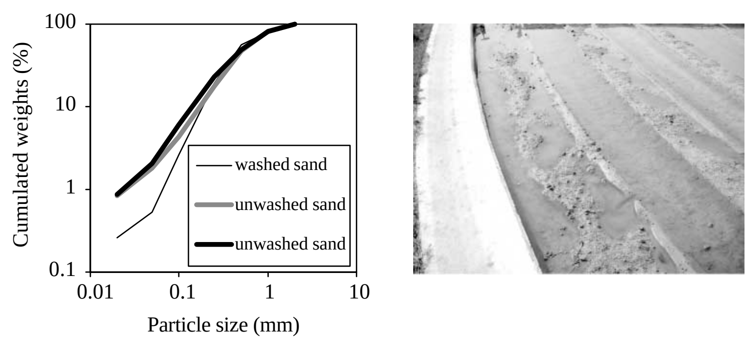

Figure 2 *Left*: particle size distribution of washed and unwashed sand of the Torrevieja II facility; *right*: flooded infiltration surface due to clay deposit

The Vall-Llobrega IP started operating in 1992, treating secondary effluent. The filter was originally constituted of dune sand with a small uniformity coefficient, $U = d_{60}/d_{10}$, equal to 2.2. After primary effluent was applied for several days in summer 1997, the filter clogged. As a significant part of the original sand had been previously lost due to different circumstances, it was decided to add about 40 cm of crushed alluvial material above the original sand. From this addition, in January 1998, the filter treated a load of $0.43\,m^3m^{-2}d^{-1}$ of activated sludge effluent, split into 10 feeding sequences a day, 5 days a week. In December 2000, a quarter of the infiltration surface was permanently flooded (Figure 3). As was also observed in other plants (Torrevieja, Sant Lluís), the persistence of impoundments at the surface of the filter had led to algae development. Degraded algae, together with organic suspended solids or clay deposits, result in a thin poorly permeable layer, which worsens the decrease of both infiltration and oxidation capacities.

The sand bed of Vall-Llobrega IPP was sampled at different depths below respectively the impounded area and the area where, conforming to the process design, water used to have completely infiltrated a short time after application. Samples were analysed for particle size distribution (Figure 4). The sand of the top 40 cm is coarser than the original dune sand and much less uniform. Below the impoundment, fines have migrated from the upper layers downward and have accumulated above the interface between the two sands. When digging into the filter, the interface layer, a few mm thin and black to dark brown, was very easily detected; its water content remained high even one week after the feeding has ceased. While most silt has been blocked at the interface, not all the clay was retained at the same depth but part of it could pass the interface and move into the dune sand. Below the well drained area, particle size distributions followed the same trend; however less fines, half the content found below the impoundments, had accumulated at the interface. When enough fine particles had accumulated at the interface, the thin impermeable layers resulting from these accumulations hindered water infiltration and gas transfer. In such circumstances, perched water saturated layers can be observed. Lasting high water saturation prevents oxygen supply, leads to local anaerobiosis, accumulation of biomass, reduction of the permeability and, eventually, permanent impoundment at the surface of the filter.

Auset (2002) could demonstrate the dramatic effect of high water saturation below the permanently flooded area. The equipment of the plant did not allow feeding of the sector containing most of the impoundment. The result was an increase from <5 to $>8\,mgL^{-1}$

Figure 3 Impoundment remaining several days after filter feeding

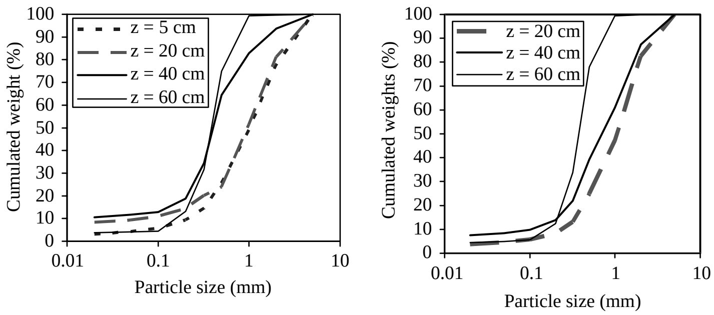

Figure 4 Particle size distribution below the impounded area (left) and the water free area (right) at Vall-Llobrega

of the dissolved oxygen content of the final effluent and an improvement from 2.4 or 2 to 4 log units of faecal coliform removal.

Design and construction

The efficiency of the treatment relies on the homogeneity of the infiltration. Uniform water spreading allows avoiding of localized overloading which would lead to clogging and performance degradation. In order to achieve uniform water distribution, all filters constructed in Spain are fed using frontal moved or centre pivot irrigation systems equipped with bubblers or special emitters designed to prevent plugging when spreading primary effluent (Figure 5).

Moreover, the infiltration surface should be maintained even; otherwise water accumulates in the depressions, leading to localized overloading, clogging risks and degraded performance. Planting turf grass on the bed surface – which is exclusively recommended for systems treating secondary effluent – helps to keep the evenness of the bed surface.

The experience is that enough care is not always taken of drainage conditions. The drainage layer, consisting of coarse gravel, should not be saturated with water and free access to the atmospheric air should be maintained. Failures of the drainage system, due to either crushing of drainage pipes during construction or to inappropriate design of drainage outlet, have resulted in the saturation of not only the bottom layer of the sand bed but, in some case, of more than half its depth; such situations were encountered at Vall-Llobrega and Els Hostalets. As not all the organic matter is fully degraded in the unsaturated part of the sand bed, the saturated bottom layers, deprived of oxygen, progressively tend to an anaerobic status. Then, over the months, anaerobic biomass develops, reducing the bed permeability. As a consequence, the water table slowly rises, worsening the situation. Digging the bed reveals sand layers with a high content of black organic matter (Figure 6). A similar situation can be observed when a soil aquifer treatment system has

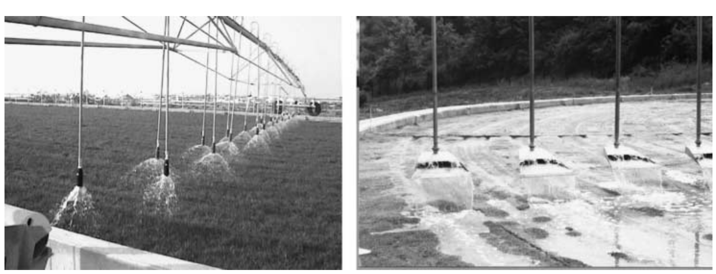

Figure 5 Emitters adopted for secondary (left) and primary (right) effluent spreading

Figure 6 Excavation in a bed clogged for misconstruction of the drainage outlet. The white line stresses the limit between the "clean" sand and the black anaerobic layer. The water of the saturated layer has invaded the bottom of the hole

been constructed upon a shallow aquifer. Then, infiltration basins may turn to leaking lagoons as was observed in the plant of Saint Gilles in La Réunion Island (France).

Hurdles to infiltration – such as manholes set in the sand bed area, as in Gabès-Tunisia pilot IPP – and every cause of preferential pathway, for instance irrigating the area above the slanting sidewall of the filter, result in lower disinfection efficiency.

Overloading

A frequent reason for IP failure is pollution overload. This may be the consequence of secondary treatment deficiencies resulting, for instance, in $N\text{-}NH_4$ excess, as was noticed in Torrevieja, of overloading of the whole wastewater treatment plant due to population growth or of the lack of knowledge of operators willing to save energy costs or increase the volume of water for reuse far beyond the capacity of the IP system. Overloading means not only that before long the design performance will not be reached, but also that the durability of the IP system is put at high risk.

Overloading means that oxygen supply does not balance the oxygen demand for organic matter and nitrogen oxidation. The first observed consequence is an increase of $N\text{-}NH_4$ content in the final effluent. Later on, the flooding of the sand bed surface lasts beyond the time usually necessary for total infiltration, meaning that the infiltration capability is diminishing. Indeed, as oxygen becomes scarce, assimilation of organic matter remains effective but is not balanced by endogenous respiration. Therefore, the biomass – which is known to be primarily developed in the upper top layer (Fox *et al.*, 2005; Rauch-Williams and Drewer, 2006) – increases, the permeability drops, from which follows the observed decrease of the infiltration capability; moreover, air phase transfer is hindered and the oxygen supply reduced. When overloading continues for several weeks, severe internal clogging occurs because the biomass evolves in anaerobic conditions, leading to organic compounds resistant to degradation. Then, and this is the worst situation for an IP system, removing the clogged sand bed may be necessary though very costly.

Less frequent internal clogging of the upper layers of the filter may result from the feeding schedule. Filters in operation are intermittently fed, flooding sequences alternating with drainage sequences, the daily number of feeding-drainage cycles, *f*, ranging between 1 and 20. It has been demonstrated that the higher the *f* value the higher the removal of faecal indicators (Brissaud *et al.*, 1999). However as shown by Bancolé *et al.* (2003), high fractionation of the daily load bears a major adverse effect. While, for low *f* values, the biofilm develops evenly over the whole depth of the bed, it accumulates in the upper layers at high *f* values. As the biomass increases, the hydraulic conductivity diminishes, reducing infiltration velocities and threatening the oxygen supply. Too high fractionation of the daily load threatens the process sustainability.

Conclusion

Deciphering the reasons for the failure or the defective functioning of IPPs is never easy; indeed, most of the design, construction and management defects affect the process in the same manner, i.e. performance degradation and clogging manifested through reduction of the infiltration capacity and lasting bed surface flooding. The most efficient and cost-effective approach has been to carry out autopsies of the failed filters, digging holes in order to observe bed vertical profiles. Variations of sand colour – unless the sand was dark black, as happens in a volcanic environment – consistency and water content are helpful clues to discover malfunctioning reasons. Analysing samples for particle size distribution, organic matter and water contents will provide useful complementary information.

Monitoring using as appropriate outfit should allow preventing malfunctioning and failure. The process deterioration manifests always in the filters as an increase of water content, due to permeability reduction, or of biomass as a result of oxygen need and supply imbalance. As 90% of the biomass is water, a close monitoring of water content of a few vertical profiles would provide the data required for a safe operation of the IP plants. Water content can be easily monitored through the measure of porous bed electrical conductivity. A piezometer should also be installed in the drainage layer in order to monitor the water level in the drainage layer.

Despite these above mentioned constraints, thanks to low O&M costs and high performance, IP, used alone or combined with UV (Salgot *et al.*, 2002) or another disinfection process, appears to be a very convenient wastewater reclamation technique for serving small and middle size communities or when dealing with sensitive areas, where classical secondary effluent cannot be disposed of without good treatment. In the Mediterranean, water flowing in temporary streams is usually re-used in a non-planned way, which makes it sensible to treat such water to high quality standards.

References

Alcalde, L., Folch, M., Tapias, J.C., Huertas, E., Torrens, A. and Salgot, M. (2007). Wastewater reclamation systems in small communities. *Wat. Sci. Tech.*, **55**(7), 149–154.

Auset, M. (2002). *Approche des mécanismes de décontamination en infiltration percolation* PhD Th., University Montpellier II.

Bancolé, A., Brissaud, F. and Gnagne, T. (2003). Oxidation processes and clogging in intermittent unsaturated infiltration. *Wat. Sci. Tech.*, **48**(11/12), 139–146.

Bouwer, H. (1996). Issues in artificial recharge. *Wat. Sci. Tech.*, **33**(10–11), 381–390.

Brissaud, F., Salgot, M., Foch, M., Campos, C., Blasco, A. and Gómez, D. (1997). Full scale evaluation of infiltration percolation for polishing secondary effluents. *Beneficial Reuse of Water and Biosolids, Water Environment Federation* Apr. 6th–9th, Marbella-Spain: 10/48-56.

Brissaud, F., Salgot, M., Bancolé, A., Campos, C. and Folch, M. (1999). Residence time distribution and disinfection of secondary effluents by infiltration percolation. *Wat. Sci. Tech.*, **40**(4/5), 215–222.

Castillo, G., Mena, M.P., Dibarrart, F. and Honeyman, G. (2001). Water quality improvement of treated wastewater by intermittent soil percolation. *Wat. Sci. Tech.*, **43**(12), 187–190.

Fox, P., Aboshanp, W. and Alsamadi, B. (2005). Analysis of soils to demonstrate sustained organic carbon removal during soil aquifer treatment. *J. Environ. Qual.*, **34**(1), 156–163.

Guessab, M., Bize, J., Schwartzbrod, J., Maul, A., Nivault, N. and Schwartzbrod, L. (1993). Wastewater treatment by infiltration percolation on sand: results in Ben Sergao Morocco. *Wat. Sci. Tech.*, **27**(9), 91–95.

Makni, H. (2001). Disinfection of secondary effluents by infiltration percolation. *Wat. Sci. Tech.*, **43**(12), 175–178.

Ménoret, C., Boutin, C., Lienard, A. and Brissaud, F. (2002). Use of recirculation through medium size granular filters to treat small food processing industry effluents. *Wat. Sci. Tech.*, **45**(12), 225–232.

Rauch-Williams, T. and Drewes, J.E. (2006). Using soil biomass as an indicator for the biological removal of effluent-derived organic carbon during soil infiltration. *Wat. Res.*, **40**(5), 961–968.

Salgot, M., Brissaud, F. and Campos, C. (1996). Disinfection of secondary effluents by infiltration-percolation. *Wat. Sci. Tech.*, **33**(10-11), 271–276.

Salgot, M., Folch, M., Huertas, E., Tapias, J., Avellaneda, D., Girós, G., Brissaud, F., Vergès, C., Molina, J. and Pigem, J. (2002). Comparison of different advanced disinfection systems for wastewater reclamation. *Wat. Sci. Tech: Wat. Supply*, **2**(3), 213–218.