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WASTEWATER TREATMENT BY INFILTRATION PERCOLATION : A CASE STUDY

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ABSTRACT

A 1,700 p.e. pilot infiltration percolation plant treated the sewage of Mazagon, a seaside resort in the South of Spain. Primary effluents, intermittently applied over twin 200 m^2 infiltration basins, percolated down to the aquifer through unsaturated dune sands. Each application sequence delivered a volume of 0.25 m^3 per m^2 of infiltration basin. Analyses of the water sampled at five depth ranging from 0.3 to 2.0 m below the infiltration surface showed that the oxidation performance of the plant was highly dependent on the applied load. Monitoring the oxygen content in the air phase of the vadose zone allowed to determine the kinetics of the oxygen stock recovery and the oxidation capability of the plant. Disappointing removal of faecal coliforms and streptococci was attributed to high pore water velocities due to infiltration heterogeneity and the high water height applied during each feeding sequence.

KEYWORDS

Infiltration percolation; oxidation; wastewater treatment

INTRODUCTION

Infiltration percolation is a low technology process used to treat primary and secondary effluents. It consists in the intermittent application of sewage on buried sand filters or permeable native soils. The infiltrated water percolates through unsaturated porous medium. The treated water is collected by a drainage system or percolates down to the underlying aquifer. When percolating through the filter, water is treated by aerobic biological processes resulting in the mineralization of organic matter and the oxidation of nitrogen compounds. In most plants, COD of the filtered water is less than 50 mg/l (Agences de l'Eau, 1993). Nitrogen is oxidized in the upper layers of the filter; residual NH4-N concentration less than 1 mg/l are not rare (Lance, 1972).

Disinfection may be very effective. Elimination of helminth eggs was always found to be complete (Guessab *et al.*, 1993). High viruses removal were found (Lance *et al.*, 1980, Gross and Mitchell, 1990, Gerba and Lance, 1978, Ho *et al.*, 1991); but recent follows up of coliphage removal in infiltration percolation plants show that our knowledge on the fate of viruses has to be improved (Brissaud *et al.* 1997). Faecal coliform removal has been often observed at the laboratory and on full-scale plants (Lefèvre, 1988, Longue, 1988, Grunnet and Olesen, 1979, Carré and Dufils, 1991, Brissaud and Lesavre, 1993). Infiltration percolation efficiency was demonstrated to be variable and mainly depending on water detention time in the filter and oxidation achievement (Brissaud *et al.*, 1998).

The air phase of the filter provides the oxygen amount required by organic matter and nitrogen oxidation. Oxygen consumption is balanced by the renewal of the air phase with atmospheric fresh air by the means of convective and diffusive exchanges trough the sand bed surface (Schmitt, 1989). Intermittent infiltration allows maximizing the convective renewal of the air phase (Boller *et al.*, 1993).

The first aim of this work was to determine the performances of the Mazagon infiltration percolation plant in the oxidation of organic matter and nitrogen. The second aim was to contribute to better describe the oxidation mechanisms in order to improve the technique. Assessing disinfection performances of the plant was a third objective.

MATERIALS AND METHODS

The pilot plant treated the sewage of Mazagon, a seaside resort located on the Atlantic coast in the South of Spain (Nieto and Alamy, 1994). The population of the village was 850 people in winter and increased up to 20,000 in summer. The plant was designed with a 1,700 p.e. capacity and in such a way that construction and operating costs were minimized. It was located on a dune coastal bar separating the Atlantic ocean from a lagoon.

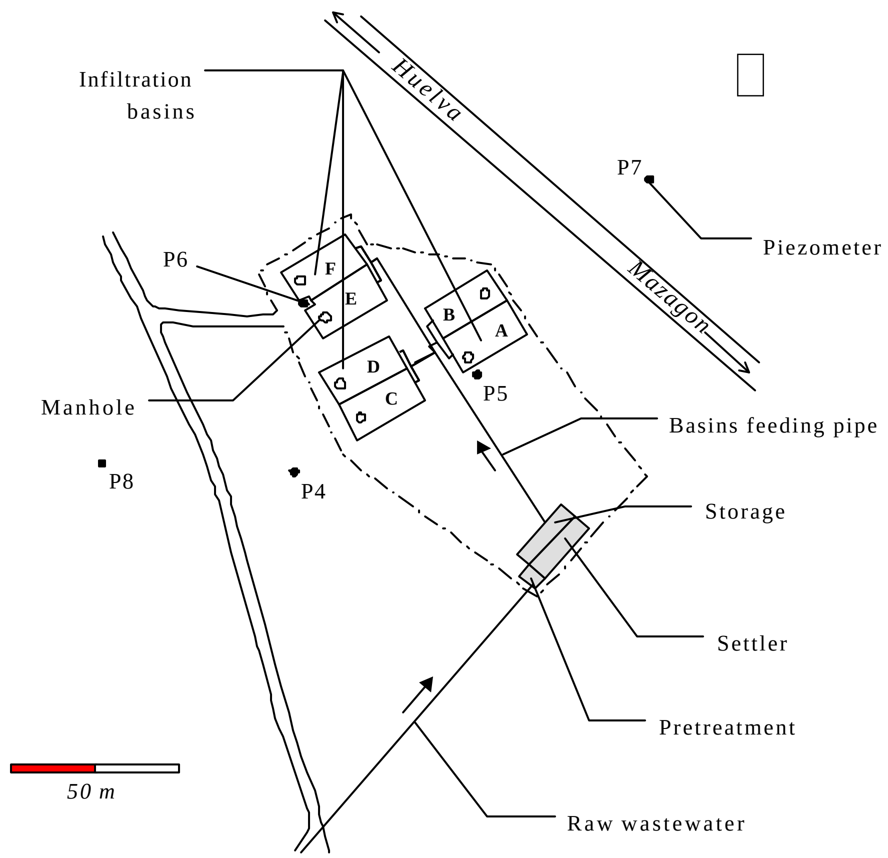


Figure 1 : Mazagon pilot plant

The plant was composed of a pretreatment (sand removal), a 170 m^3 primary settling tank, a storage tank and three pairs of 200 m^2 infiltration basins delimited in the dune area (figure 1). The gravity feeding of infiltration basins with stored primary effluents was controlled by a self-releasing siphon. Approximately 100 m^3/h wastewater were delivered during each sequence, simultaneously feeding two twin infiltration basins. Manual valves allowed to select the pair of basins to be fed. A feeding sequence lasted between 40 and 50 minutes, corresponding to a 130 m^3 mean flow rate. Primary effluents were spread over the surface of the sand filters by way of slotted pipes (figure 2). An operating schedule of one or two application sequences a day had been adopted during the investigation.

Samples taken when drilling the observation wells showed the sand was homogeneous, with a d_{50} of 240µm, a uniformity coefficient, d_{60}/d_{10}, of 2.3 and a SiO_2 content of 94%. A manhole was bored in each basin (figure 2) and equipped for water and gas sampling and temperature monitoring at 30, 60, 100, 150 and 200 cm depth. Five piezometers, P4 to P8 (figure 1), were drilled for water table monitoring and groundwater sampling. The water table was between 5.1 to 6.6 m below the infiltration surface, depending on the pair of basins.

Behaviour and performances of the plant have been investigated during a period of five months, from March to August 93. Over eighty application sequences have been monitored; primary and percolating water have been analysed for thirteen sequences. Chemical and microbiological analysis have been performed on primary effluents, percolation water at five different depths along the unsaturated sand profile and the groundwater. COD, $N-NH_4$, $N-NO_2$ and $N-NO_3$ were analyzed using a Hach DR/2000 spectrophotometer.

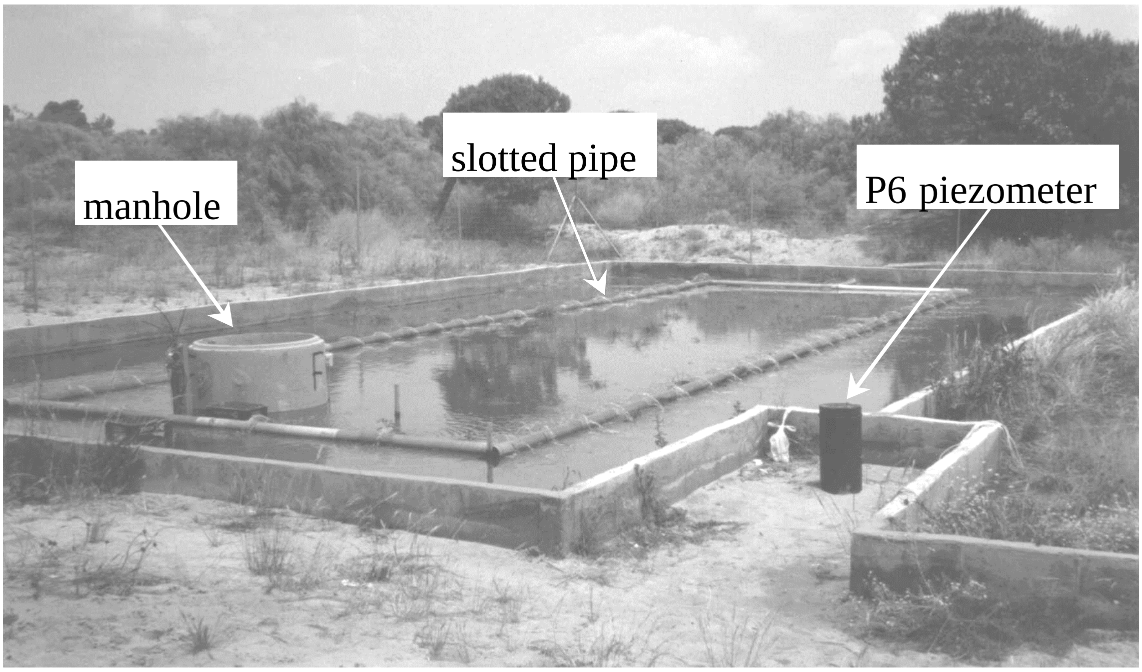


Figure 2 : F infiltration basin

Dissolved oxygen, pH and electric conductivity were measured with a WTW field probe. Faecal pollution indicators were counted according to spread-plate procedure and membrane filtration technique. Water and soil temperatures and groundwater level were monitored.. Soil air phase has been analyzed at five different depths for oxygen, carbon dioxide and nitrogen, using a Hermann-Moritz CP4 chromatograph.

Important changes due to climatic and population variations were noticed in the quality and available amount of urban wastewater during the study period (table 1). Three cases were investigated in order to evaluate the effects of hydraulic load and seasonal variations in the quality of urban wastewater on infiltration percolation : (i) one application sequence per day in spring season, and, (ii) one application and (iii) two application sequences per day in summer season over the operating basins.

RESULTS

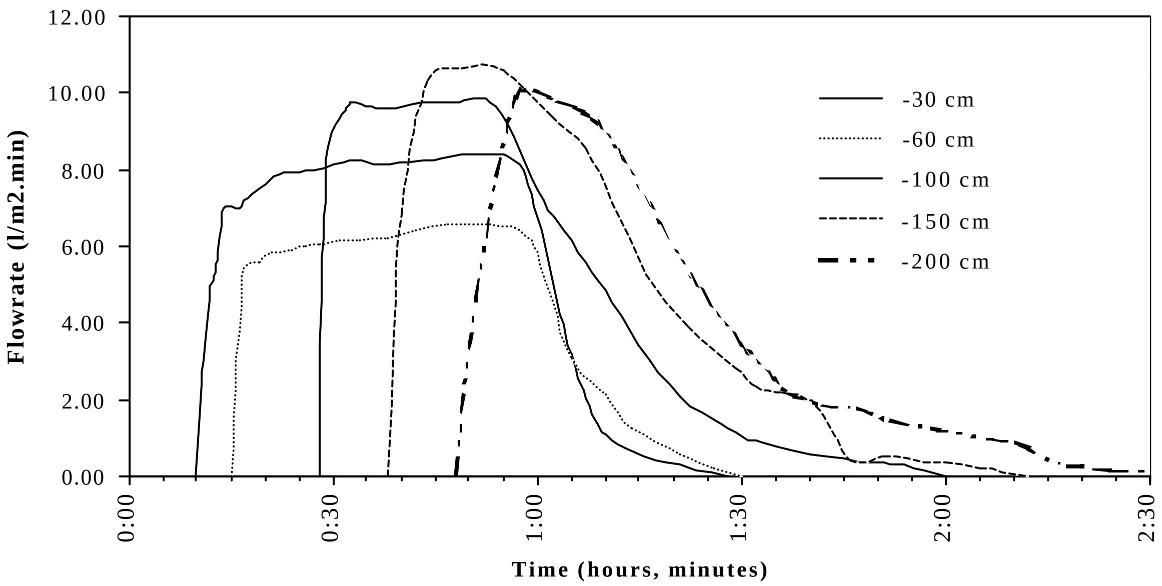
Hydraulics

Primary effluent was not homogeneously spread over the infiltration surface. Only half the surface was flooded after 5 minutes feeding, 75 % after 12 minutes and about 90 % after 21 minutes. Similar evolutions were observed in the uncover of the sand surface after the feeding had ended. This drawback was due to :

- a low flooding rate according to the infiltration surface and the sand permeability,
- a non uniform yield delivered along the distribution pipes,
- unevenness of the infiltration surface - despite frequent raking - because of non uniform sand packing during the infiltration periods and sand blowed the wind.

It resulted in an important heterogeneity of the effective load applied over basin surfaces.

Water transport in the soil profile was observed through the measures of soil electric conductivity and the flow rate collected by the samplers. Both measures are correlated with the water content. They illustrated the downward progress of the water pulse after a feeding sequence (figure 3). A rapid transport was demonstrated. As an example, an amount equivalent to 95% of the water applied during a feeding sequence had moved beyond 2.0 m depth 2 hours after the feeding had started. Data suggest high pore water velocities which were the consequence of the 0.25



m^3/m^2 water height applied during each feeding sequence, locally enhanced by overloadings. Each application resulted in a 0.50 m raising of the water table.

Figure 3 : Flow rates in the samplers (the feeding sequence started at t = 0. Recovered volumes differ because of infiltration heterogeneity)

Oxidation performances

The filtered water quality was observed to vary during a sequence. Mean values were used to determine treatment performances. TOD, the total oxygen demand, is calculated as $COD_{dissolved}$ + 4.57 NK. Kjeldahl nitrogen content was not measured but estimated according to the literature (Lance *et al.*, 1980, Carré and Dufils, 1991, Rice, 1974, De Vries, 1972, Cochet *et al.*, 1989); it was assumed to be 1.2 times the $N\text{-}NH_4$ content.

(i) and (ii) : For one application per day, average performances in organic matter removal and nitrogen oxydation were high (table 1). Whatever the season and the applied pollution load, ammonium and COD removals reached 98% and more than 87% respectively two meters below the infiltration surface. High nitrification rates led to high nitrate production ; nitrates have been detected in the aquifer. In summer, ammonium removal was not completely balanced by nitrate production, meaning that some denitrification had occured.

Table 1 : Average characteristics of primary effluents and filtered water sampled at 2 m depth, for one application a day (hydraulic load of 0.25 m/d).

	T (°C)	pH	O_2 (mg/l)	Cond. (µS/cm)	COD (mgO_2/l)	NH_3 (mgN/l)	NO_2 (mgN/l)	NO_3 (mgN/l)	TOD (mgO_2/l)
					Spring season *				
Primary effluent	19.9	7.3	1.2	904	279	31.5	0.02	2.3	462
Filtered water	20.6	6.8	5.6	1155	36	0.5	0.08	28.2	38
Removal rate					87 %	98 %			92 %
					Summer season**				
Primary effluent	25.9	7.1	0.8	1082	408	53.8	0.02	3.0	720
Filtered water	26.4	6.3	4.3	1389	35	0.3	0.14	32.4	37
Removal rate					91 %	99 %			95 %

*   *average values of 4 sequences*   **   *average values of 3 sequences*

(iii) : the 2 sequences schedule was implemented for a short period, during the summer season. Every day, the first sequence was delivered in the morning and the second in the afternoon. So, the duration of the drainage sequences was 18 and 5 hours before the morning and the afternoon applications respectively. Two meters below the soil surface, mean COD was higher than for one application a day but no more than 50 mg/l, without significant difference between morning and afternoon sequences. At the same depth, N-NH_4 and N-NO_2 mean concentration values, 11 and 6 mg/l respectively, showed that total oxidation was far from being achieved. The conclusion was that 2 feeding sequences a day brought about a depletion of the soil oxygen stock and non sustainability of the process. The time between two applications was too short to allow the recovery of the oxygen stock. The importance of the drainage sequence length was demonstrated by the difference between mean N-NO_3 concentrations measured after the morning and the afternoon sequence : 75 and 13 mg/l respectively.

Oxidation mechanisms

Water quality analyzes demonstrated that oxidation activity was mainly located in upper sand layers : approximately 60% COD was removed and 35 to 50% of ammonium oxidized in the top 30 cm of the sand profile. However, lower layers significantly contributed to water treatment performances (figure 4). The reason is that wastewater infiltrated rapidly and deeply into the filter because of the high water height applied during each feeding sequence.. A fraction of it left the upper layers without total COD removal and ammonium oxidation. Oxidation was achieved in lower layers, entailing air phase oxygen uptake and dissolved oxygen increase, as shown by figure 5. Percolation water quality was dramatically improved at 2 meters depth.

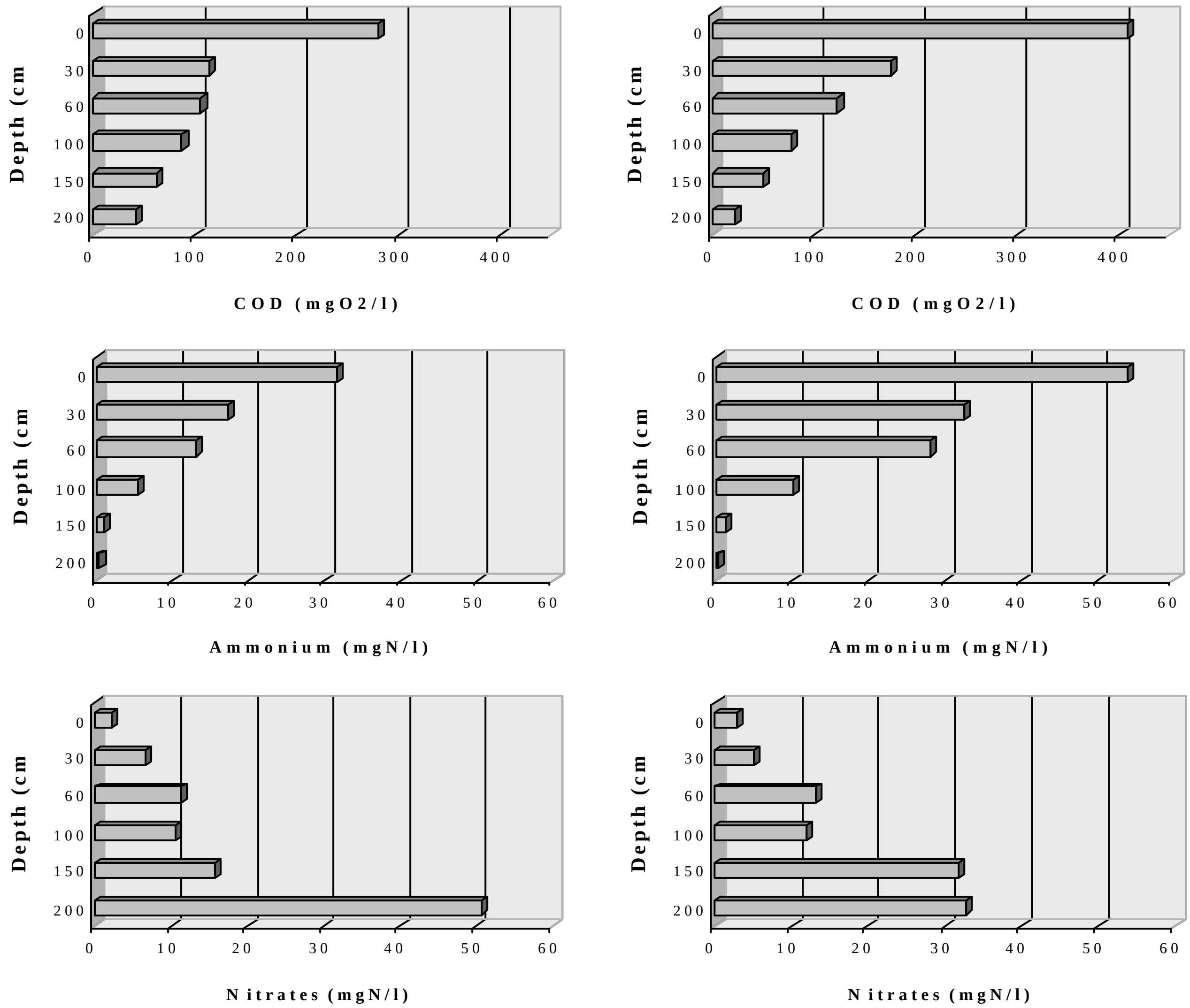
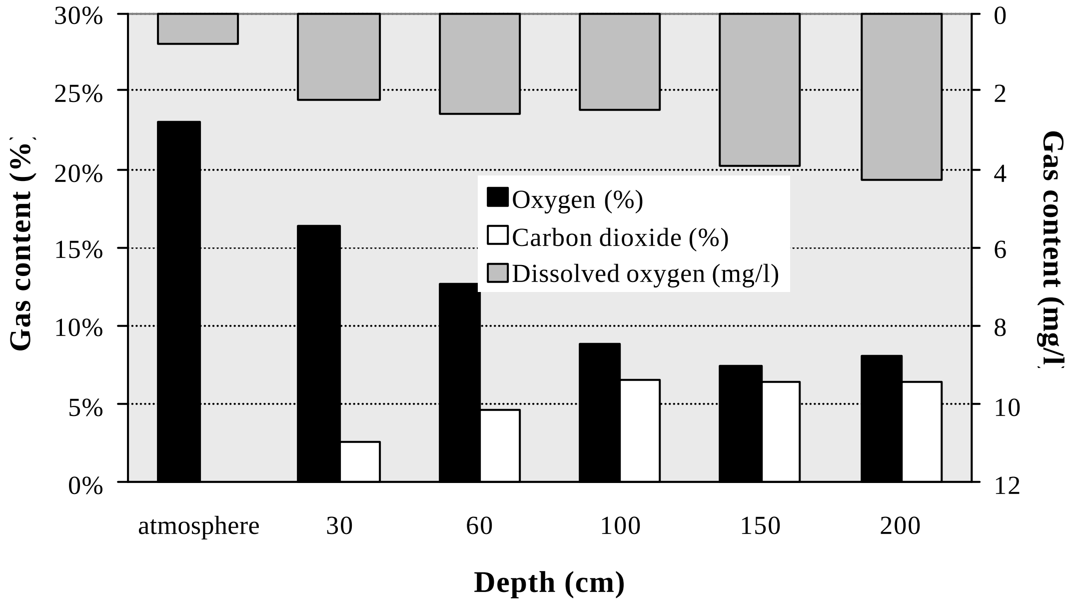


Figure 4 : Average COD and N-NH4 and N-NO3 content profiles, below infiltration basins D and F, during an application-drainage period on June 23, 1993.

Vertical profiles of oxygen and carbon dioxide contents, measured every day just before the water was applied, showed slight variations over the monitoring period. Oxygen content was decreasing and CO_2 content decreasing from the surface to 1.5 m depth (figure 5). Oxygen content was high enough to allow further oxidation in the lower sand layers. But the time interval between two applications was not long enough to evacuate the carbon dioxide that resulted from organic matter mineralization nor to recover oxygen atmospheric air concentration in the soil air phase.

Figure 5 : Oxygen and carbon dioxide contents in the gas phase before morning feeding and mean dissolved oxygen wastewater



content.

Air phase analysis carried out throughout infiltration-drainage sequences contributed to the understanding of the oxidation processes and the role of gas transfers in oxygen supply and CO_2 discharge. A quick drop of oxygen concentration was observed in upper sand layers just after primary effluent application had started ; it was due to consumption by organic matter and nitrogen oxidation. A slow restoration of the soil oxygen stock followed (figure 6). About 15, 24 and 30 hours were needed to recover the oxygen concentration measured at 0.3, 0.6 and 2 m depth before the feeding sequence. As water and air convective movements in the 2 m upper layer of the filter had virtually ceased 2 hours after a feeding sequence, most of the oxygen renewal was the result of diffusion in the soil air phase.

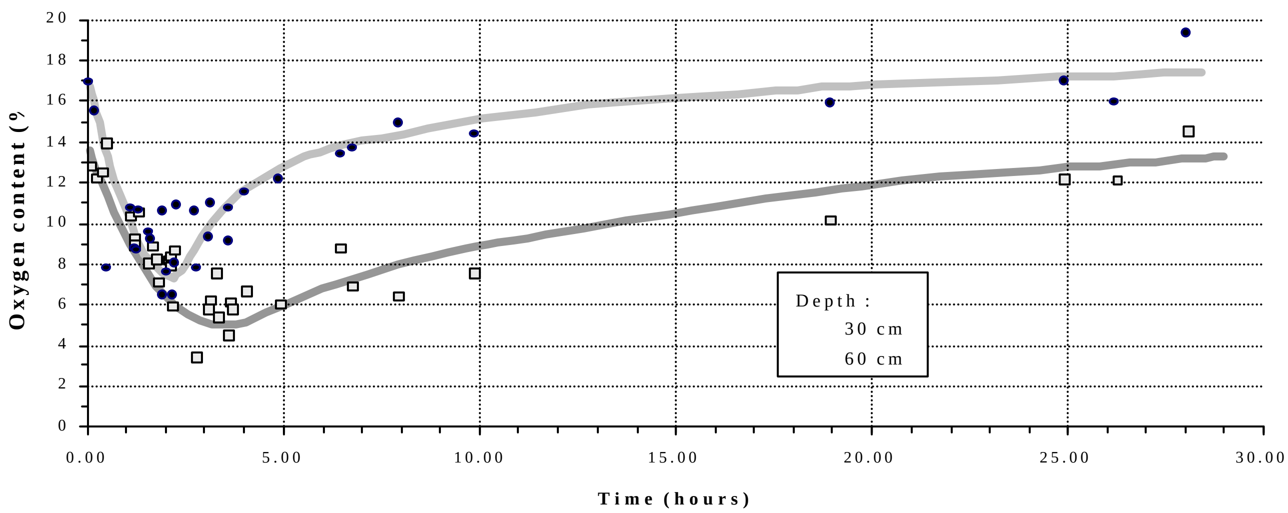


Figure 6 : Soil oxygen concentrations at 30 and 60 cm depth (zero time coincides with the very beginning of wastewater feeding sequence).

One application sequence a day let just the time that was necessary to balance oxygen consumption and make the process sustainable. The oxidation capability was calculated to be about 680 mg/l for the 0.25 m/d hydraulic load applied. This high capability was due to high summer temperatures (Makni, 1995) . According to Schmitt (1989), a higher daily hydraulic load could have been treated when fractionning it in 2, 3 or 4 application sequences a day, allowing higher diffusive oxygen supply.

Disinfection performances

Total coliform, faecal coliform and streptococci contents were measured for 7 consecutive sequences. Slight content decreases were observed . Average removals, $\Delta_m = \log (C_i/C_o)$, with C_i and C_o microorganism contents in primary effluents and percolation water, were 1.2 for total coliforms, 1.6 for faecal coliforms and 1.3 for faecal streptococci at two meters depth (figure 7). These poor performances can be explained by the high pore water velocities resulting from the 0.25 m water height applied during each feeding sequence. Because of very noticeable infiltration heterogeneity, water heights actually infiltrated were locally higher than 0.25 m; they could have reached 0.5 m in some places. As observed in other plants (Brissaud and Lesavre, 1993), small removals occur when water residence times in the filter are low. The detrimental effect of high water heights has been demonstrated by Brissaud *et al*. (1998).

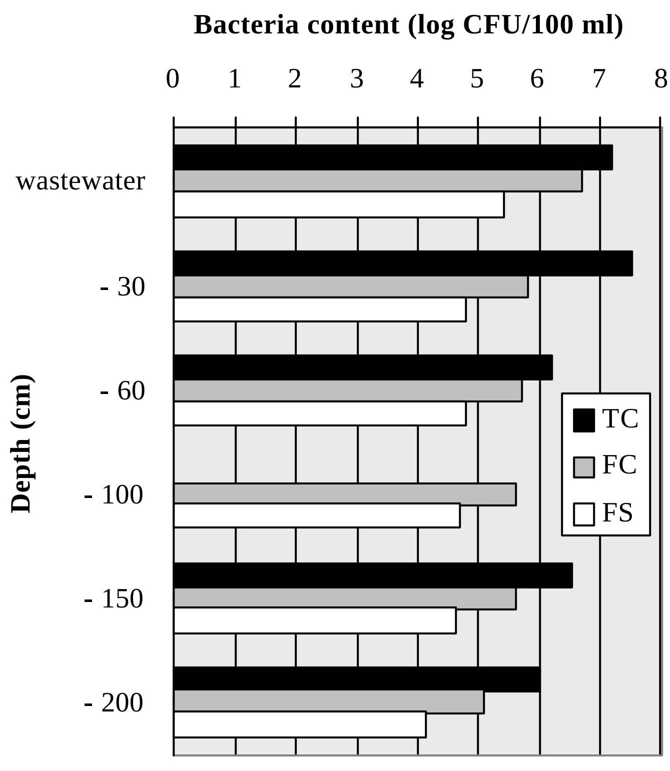


Figure 7: Mean bacteria removals along the soil profile

CONCLUSION

Oxidation performances of infiltration percolation in Mazagon dune sand were very high provided the hydraulic load did not exceed 0.25 m per day. Ninety percent COD was removed and more than 98 % N-NH4 oxidized.

Monitoring oxygen content in the soil air phase showed that restoring the oxygen stock, thus ensuring the process sustainability, took about one day time after a 0.25 m application. It demonstrated that the hydraulic load that could be treated was not higher than 0.25 cm per day. Tests confirmed that treating 0.50 m per day, with 2 feeding sequences a day was not feasible. These results were obtained according to water heights, h, delivered during each feeding sequence equal to 0.25 m. Literature data suggest that higher hydraulic loads could have been treated with smaller h values ; unfortunately, it could not be checked in Mazagon for practical reasons.

Disinfection performances were disappointing because of a too high h value and heterogeneous infiltration. Practical lessons can be learned from these experiments, especially the significance for the treatment performances of a homogeneous spreading of the sewage water on the infiltration area, that can be reached by appropriate feeding systems and flow rates. Maintaining infiltration surface evenness helps providing uniform infiltration. Delivering small water heights during each feeding sequence should also be recommended.

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